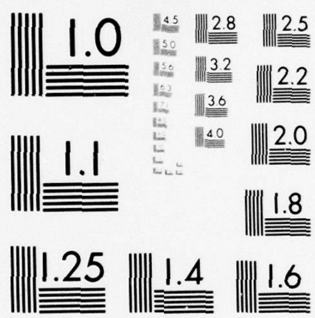
AD-A064 401 SPERRY SECOR FAIRFAX VA F/G 14/2
AH-64 FLIGHT AND WEAPONS SIMULATOR CONCEPT FORMULATION STUDY. V--ETC(U)
SEP 77 J L DICKMAN, H KESTENBAUM, P W CARO N61339-77-C-0048
UNCLASSIFIED SE-622-CFS-114-VOL-2 NL

1 OF 3
AD
A064401



MICROCOPY RESOLUTION TEST CHART

LEVEL III

ADAMS (1)

SPERRY

SECOR
SIMULATION SYSTEMS

2724 DORR AVENUE
FAIRFAX, VIRGINIA 22030
TELEPHONE (703) 573-2030

SE-622-CFS-114

LEVEL III

1

10 Joseph L. Dickman, Howard Kestenbaum, Paul W. Caro, Carol O'Neill Charles Sinclair

14 SE-622-CFS-114-VOL-2

15 N61339-77-C-0048

AD A064401

DDC FILE COPY

6

AH-64

FLIGHT AND WEAPONS SIMULATOR

CONCEPT FORMULATION STUDY.

Volume II.

9 Final Report,

12 239 p.

Prepared by:

Sperry SECOR
2724 Dorr Avenue
Fairfax, Virginia 22030

Prepared for:

Naval Training Equipment Center
Orlando, Florida 32813

11 Sept 1977

393 444

TABLE OF CONTENTS

Volume I

Contents:

Volume II

Volume III

LIST OF ILLUSTRATIONS

Volume I

Volume II

Volume II (Cont.)

Volume III

LIST OF TABLES

Volume II

Volume III

SECTION IV

ANALYSIS OF COMPONENTS AND TECHNOLOGY

This section of the study addresses the components that will make up the trainer - the cockpit module, motion system, visual system, computer, and interface - and the principal supporting areas - reliability, maintainability, and integrated logistics support. Current technology is examined; trade-off analyses are conducted; the best technical approaches, it is believed, are selected; and cost effectiveness evaluations, when possible, are made. Conclusions and recommendations, with respect to the various areas studied, are made throughout.

COCKPIT MODULE

Selection of the optimum configuration for the cockpit module must take into account the various modes in which the trainer will be used, constraints imposed by the selected visual system module, and constraints imposed by the instructor/operator module. Various configurations for the cockpit module for the AH-64 Flight and Weapons Simulator (FWS) are possible. These include:

1. Separate cockpits for pilot and copilot/gunner.
2. Combined cockpit module to include pilot and copilot/gunner in the actual aircraft arrangement.
3. Combined cockpit module with on-board instructor's station.

The approved training device requirements (TDR) for the AAH-FWS envision that the AAH-FWS will be used in two modes: (1) an integrated mode for simultaneous pilot and gunner training, and (2) an independent mode for pilot training in the rear seat and copilot/gunner training in the front seat. For simultaneous training of pilot and gunner the most cost effective arrangement is a combined cockpit module with the pilot and gunner arranged in the actual aircraft configuration.

The major advantage of this arrangement over a separate cockpit arrangement is the reduction of hardware requirements which in turn reduces the overall requirements for maintenance and logistic support. The combined cockpit module requires only a single motion system, one control loading system to activate both the pilot and copilot/gunner flight controls, and one visual display for both the pilot and copilot/gunner. If the pilot and copilot/gunner stations are made separate modules, the motion system, control loading system, and visual systems must be duplicated for each cockpit. In addition to the additional equipment required for this arrangement, the design of this equipment and the computer programs that supply the drive signals must insure accurate synchronization between the two cockpit modules. All of this increases the overall cost of equipment and cost of operation, and reduces the reliability of the overall training system.

A combined cockpit module with pilot and copilot/gunner arranged as in the actual aircraft tends to define the visual system display module. Space limitations rule out the use of a single virtual image, infinity optics display system. There are no virtual image displays with exit pupils large enough to accommodate the five-foot distances between the pilot's and copilot/gunner's heads. The alternative would be to use a projected image wraparound screen system. This approach would require a large screen radius to minimize the perspective distortion for either or both the pilot and copilot/gunner due to their different eye locations.

An alternative approach would be to separate the pilot's and copilot/gunner's stations on a common motion system and provide separate virtual image displays for each station. Present designs of six-post motion systems are capable of accommodating such an arrangement. This arrangement has the advantage of a single motion system, one set of control loading units, and one visual image generator. A single image generator would supply the same visual image signals to both the pilot's and copilot/gunner's display units.

The two cockpits would be mounted in tandem, but separated by the distance required by the virtual image display surrounding each cockpit. This would allow the single motion system to provide the proper sensory input for the two crewmen. Each would see an identical wide angle display made up of multiple virtual image displays surrounding his cockpit.

Key among the negative features of this approach is the sacrifice of the realistic tandem seating arrangement with the pilot seeing the CPG and the CPG seeing the pilot in his mirror. Especially in mission simulation, it is considered that the crew arrangement of the real aircraft should only be given up if no viable alternative to the virtual image display could be found. Other negative features of this approach include: high weight handling capacity needed for the motion system to handle two cockpits plus two display complexes; problems in obtaining uninterrupted wide fields of view with mirror-beam splitter virtual image displays, or with inline infinity optics; resultant expense and low light levels achievable in the display; and ingress-egress problems with the multiple virtual image display surrounding each crewman's seat.

Thus, because a configuration that obviates the need for the virtual display is available, the alternative approach is not recommended.

Separate Cockpit Configuration

An argument against the combined cockpit arrangement discussed above is that both integrated and independent modes of operation are required. The single motion system would preclude simultaneous gunner training in the front seat and pilot transition training in the rear seat. Thus, for independent operation, utilization of the AAH-FWS trainer would be limited to one seat at a time.

Separate cockpits, each with its own motion system, flight controls, and visual system would provide maximum flexibility of

AAH-FWS trainer utilization. In the integrated mode both seats would be operated in a synchronized manner to provide gunner training for the front seat and pilot training for the rear seat. In the independent mode of operation the front seat module would provide gunner or copilot system training while at the same time the rear seat module could be used to provide pilot flight training.

The use of flight controls and motion simulation at the front seat would only be required for copilot flight training. When used for independent gunner training the helicopter would be flown by the computer or by the instructor. Also, during independent gunner training there would be no need for full motion simulation. An inexpensive one or two degree-of-freedom limited excursion random motion would be adequate.

Part Task Gunner Trainer

A compromise approach would consist of a combined front and rear seat cockpit FWS configured to provide integrated pilot and copilot/gunner training and independent flight training for both pilot and copilot. A separate part-task trainer configured to provide gunner training would be included to train gunners to detect and recognize targets and use the AAH weapon systems.

This arrangement proves to be the most cost effective in terms of hardware requirements. It has the advantage of a combined cockpit module in that only one motion system and control loading system is required. The cockpit module for the gunner part-task trainer would be a simplified reproduction of the AH-64 front cockpit either mounted on a two-degree of freedom, limited excursion, random motion system, or using a seat shaker vibration/buffet system. The flight and engine controls would not be activated, and all avionic instruments and panels not required for gunner training would be two-dimensional photographic facsimilies.

On-Board Instructor Station

From past experience it has been found that an on-board instructor station has many training advantages. It places the instructor in close proximity to the trainees where he can observe their actions and observe the same instruments and displays that they are using. A secondary advantage is the possible reduction in the number of instructor repeater instruments and visual monitors in cases where the instructor can see the trainee's instruments and visual display.

The arrangement placing the instructor's station on the motion system directly in back of the pilot and copilot proves very successful in the case of transport type aircraft and HH-3 or HH-53 type helicopters where the pilot and copilot are seated side by side and there is an excellent view of the instrument panel and controls from the instructor's position. In this arrangement the instructor is essentially in the cockpit.

The arrangement of the AH-64 cockpit precludes the arrangement described above. The tandem arrangement of pilot and copilot/gunner with the pilot behind and above the copilot/gunner would require that an on-board instructor's station be located outside the cockpit canopy. It is concluded that there is no location that would provide an instructor a useable view of both the pilot and copilot/gunner. In addition, any location of the instructor that provided a view of the trainees would interfere with the wide angle visual display.

Recommended Cockpit Module Configuration

It is recommended that the AAH-FWS training system consist of two trainer (cockpit) modules. First, a combined pilot and copilot/gunner cockpit, mounted on a six degree of freedom motion system, be provided for integrated pilot/gunner training and individual pilot or copilot flight training. Second, a part-task gunner cockpit either mounted on a two-degree of freedom, limited excursion,

random motion system or using a seat shaker system be provided for training gunners to detect, recognize, attack, and destroy hostile targets.

It is recommended that the instructor station for the integrated cockpit be located off the motion system. However, the instructor station for the part task gunnery trainer can be located adjacent to the gunner trainee in such a position that the instructor can view the high resolution visual display.

Cockpit Module Construction

The cockpit module of the AAH-FWS should be a realistic reproduction of the pilot and copilot/gunner stations of the AH-64 helicopter. As a minimum the section of the AH-64 helicopter fuselage between stations 35 and 177 should be represented by the AAH-FWS cockpit. It is considered essential that the simulated cockpit provide a realistic cockpit environment in which the trainees can be given effective training. To accomplish this the AAH-FWS cockpit must duplicate all AH-64 helicopter instruments, controls, furnishings, equipment, and all other significant items that will be visible to, or operated by the trainees.

The wide-angle out-the-window visual simulation requirement for the AAH-FWS requires that greater than normal consideration be given to the external configuration of the trainer cockpit module. In particular, the canopy and window portions of the AH-64 helicopter must be duplicated in the AAH-FWS cockpit. Because the fields of view available to the pilot and copilot/gunner are determined by the windshield and window structure it is essential that these structures be duplicated in the AAH-FWS cockpit. In addition, the effects of the window glass in producing reflections of cockpit lighting during night operations are important considerations and must be taken into account in the AAH-FWS.

The external configuration of the AAH-FWS cockpit below the sill line has little or no effect on training. Therefore, for

cost considerations the fuselage contours may be approximated with flat surfaces.

<u>Cockpit Structure</u>

In the past, simulator cockpits have been constructed using various techniques, such as:

1. Molded fiberglass shells.
2. Sections of actual airframes.
3. Aluminum frame and skin structures.

All these techniques, and others, serve the purpose of providing an enclosure for the trainees and provide structural support for panels, controls, and furnishings. Experience, however, has been that fiberglass shells or actual airframe structures do not allow installation of adequate access provisions for maintenance. In the case of the AH-64, where the equipment in both cockpits is very compact, provision must be made for access through the cockpit shell for maintenance.

The preferred technique for providing adequate access for maintenance would be to design and construct the cockpit using a structural aluminum frame with removable skin panels attached with quarter-turn fasteners. This will provide ready access for maintenance of equipment in the side consoles and front and rear sections of the cockpit module. The cockpit frame should include a rigid base structure, able to support without deflection the flight controls and their push-pull rods. The structure should form the cockpit sides up to the canopy sill line, include bulkhead structures to support the instrument panels, and provide supports for the pilot and copilot/gunner seats.

As discussed above, the canopy and windows must duplicate the appearance and optical function of the actual airframe components. The best method for accomplishing this would be to use actual airframe components.

Ingress and Egress

Ingress to and egress from the AH-64 helicopter cockpit is through the two canopy door panels on the right side. The configuration of the seats and side consoles in the AH-64 helicopter cockpits precludes any method of ingress and egress except over the cockpit sill. Thus, since it is recommended that the canopy above the sill be actual or reproduced airframe components, ingress and egress can best be provided by using the two canopy door panels on the right side. This would provide ingress and egress the same as it is in the actual AH-64 helicopter.

Mounting

An aluminum alloy cockpit base frame weldment should be provided to serve as (1) a mounting for the cockpit shell structure, (2) the floor in the pilot and copilot/gunner stations, (3) a mounting of the flight controls and linkages, (4) a mounting for the consoles, seats, and other interior aircraft furnishings, and (5) an interface between the cockpit module and the motion system module. The lower surface of the cockpit base frame should be provided with structural attachment members to allow bolting to the cockpit motion system platform structure. It is essential that the cockpit base frame have sufficient strength and ridigity to transmit all acceleration and vibration forces from the motion system platform to the cockpit components.

Recommendations

It is recommended that the AAH-FWS cockpit module consist of an aluminum frame, aluminum skin reproduction of the AH-64 helicopter fuselage section between stations 35 and 177 supported on a welded aluminum structural base frame. All the aluminum skins should be removable, secured by quarter-turn fasteners, to allow maximum access through the cockpit exterior for maintenance.

The recommended construction of the canopy and windows above the sill line consists of using actual airframe components or

reproductions of these components. Ingress and egress would then be provided through the two right side door panels, as in the actual aircraft.

Flight and Engine Controls

The AH-64 helicopter primary flight control system is an irreversible dual-boosted hydraulic system which positions the main and tail rotor blade pitch in response to pilot control movements. The cockpit controls consist of cyclic stick, collective stick, and directional pedals. The pilot's set of controls are mechanically connected to the copilot's controls and to the primary flight control actuators through a system of push-pull rods and bellcranks. Since the hydraulic boost system is irreversible, preventing any feedback of aerodynamic forces to the controls, artificial feel and trim control are provided by bungee springs in parallel with each control channel. Trim adjustment is provided by the pilot adjusting the neutral position of the bungee spring.

In addition to manual flight control there is a three-channel, (roll, pitch, and yaw) automatic stabilization equipment (ASE) system in series with the pilot's controls. This system provides an electrohydraulic input to the flight controls that has a maximum authority of 10 percent of manual authority to provide stability augmentation. In addition the ASE provides an electrical back-up flight control system that can be used by either the pilot or the copilot to control the helicopter in case of damage to the mechanical control system. When activated, this system disconnects the mechanical control input to the flight control actuators and provides electrohydraulic control from electrical transducers attached to the flight controls.

The primary flight control hydraulic actuators are powered by two separate hydraulic systems (flight control hydraulic system and utility hydraulic system) in tandem arrangement. Either system alone can provide full flight control. However, if both hydraulic

systems are failed, controlled flight is not possible. To cope with this emergency each flight control channel has a hydraulic accumulator that stores sufficient hydraulic power to make a safe landing following a complete hydraulic power failure.

Engine Controls

In the AH-64 helicopter the turbine engines are controlled by power lever quadrants located on the left console of both the pilot and copilot/gunner stations. The two quadrants are mechanically connected together and to the engine fuel controllers. Thus the engines can be controlled by either the pilot or copilot.

Extent of Simulation

The AAH-FWS will provide transition training and standardization/proficiency training in the AH-64 helicopter. To provide effective training in these areas the AAH-FWS must possess fully activated flight and engine controls, to include:

1. Pilot and copilot cyclic sticks.
2. Pilot and copilot collective sticks.
3. Pilot and copilot directional pedals.
4. Pilot and copilot engine control quadrant.
5. ASE controls.
6. Trim controls.
7. Back up control system.
8. Wheel brakes.
9. Rotor brake control.

Accurate force-feel characteristics of all the pilot/copilot operated controls must be reproduced for all modes of operation throughout the full operating envelope of the AH-64 helicopter. All pilot/copilot controlled adjustment controls such as friction locks and pedal position adjustments must operate as they do in the operational aircraft.

In addition to accurate simulation of all normal operation, the above controls must be made to feel and respond correctly to

all anticipated system failures and combat damage such as:

1. Loss of flight control hydraulics.
2. Loss of utility hydraulics.
3. Loss of both hydraulic systems.
4. Trim failures in each channel.
5. ASE failures in each channel.
6. Severed control rod in each channel.
7. Engine hot start, flame out, etc.
8. Fuel system failures.
9. Fuel controller failures.
10. Engine oil failures.

For all failures, simulation of all related and dependent aircraft systems and the aerodynamic performance of the helicopter should be provided.

To provide efficient standardization and proficiency training the flight control systems should include provisions for recording and playing back segments of a mission. Playback should be provided for recording the performance of a trainee for later playback for critique. Also it should be possible to record demonstration missions to be played back for trainee instruction.

Techniques are readily available to activate and provide accurate simulated force-feel loading to all the AH-64 helicopter flight and engine controls. A system of loading units using electrohydraulic force actuators in combination with bungee springs reproducing the artificial feel springs has been successfully used to simulate helicopter flight controls.

<u>Recommendations</u>

An economical approach to the design of the flight and engine controls for the AAH-FWS is recommended, as follows. Actual airframe control systems (collective, cyclic, directional pedals, and engine quadrants) should be installed in the pilot and copilot/gunner stations of the cockpit. Airframe components should be

installed between these controls and the space behind the pilot's seat. Electrohydraulic/bungee spring loading units can then be installed back of the pilot's seat to provide loading forces to each control. This arrangement would provide optimum maintenance accessibility.

All flight, engine, and secondary controls should be fully activated to provide accurately simulated force-feel characteristics. All related helicopter systems and aerodynamic performance should respond correctly to all pilot control inputs and instructor inserted failures.

The control loading systems for the primary flight controls should include provision for recording all pilot control actions. The systems should then be able, under instructor control, to play back these control actions.

Cockpit Module Environment

Heating and cooling air to maintain comfort conditions in the pilot and copilot/gunner stations in the AH-64 helicopter are provided by an air cycle environmental control unit. This unit normally uses compressed air from the shaft driven air compressor or, in case of failure of this air supply, from the engine bleed air system. Cockpit temperature is controlled by an adjustable thermostat at the pilot's station.

Extent of Simulation

The results of a study of the AH-64 helicopter environmental system and the pilot's tasks show that simulation of the environmental control system should be limited to activation of the caution and warning lights and controls associated with the ice detection and de-icing systems. Simulation of the air conditioning and defogging systems is not required. However, provision should be made to maintain comfortable conditions in the cockpit since these spaces will be completely enclosed by the cockpit shell and canopy.

The AAH-FWS will be installed in an air conditioned building; therefore, there is no need to provide heating to the cockpit spaces. The only requirement should be for a supply of ventilation air and cooling air.

Aural Simulation

For realistic training, the AAH-FWS cockpit module should present to the pilot and copilot/gunner the same environment that they would experience in the AH-64 helicopter. Thus an arual simulation system must be provided to reproduce the following sounds:

1. Engine sounds.
2. Gear box sounds.
3. Rotor and fuselage sounds.
4. Sounds from auxiliary systems.
5. Sounds from weapon operation.
6. Sounds from hostile weapons.

Recommendations

It is recommended that the AAH-FWS include an air conditioning unit designed to deliver a constant supply of filtered ventilation air to both the pilot's and copilot/gunner's space. This air conditioner should be external to the cockpit module and should be designed to cool the ventilation air supply sufficiently to maintain a temperature of 55°F in the cockpit with an ambient air temperature ranging between 70°F and 110°F. Control of the temperature in the cockpit should be by means of a thermostat set by the pilot's temperature control.

It is also recommended that the AAH-FWS cockpit module include an aural simulation system that will accurately synthesize all engine, gear box, rotor, auxiliary system, and weapon release sounds. The simulation must be realistic for all operational modes, and throughout the performance range of the AH-64 helicopter.

Instrument and Control Simulation

The AH-64 FWS will be used to train pilot's and gunner's to perform all basic aircraft maneuvers including preflight checks, engine starting, taxi, takeoff, enroute flight and navigation, approach to and engaging hostile threats, approach to landing area, landing, and engine shutdown. In addition it will be used to train the pilots and gunners to effectively detect and cope with a wide

range of system malfunctions due to equipment failure or hostile weapon strikes. The primary source of information to the trainee pilots and gunners to enable them perform these tasks in the AH-64 FWS will be the instruments in the cockpits. Thus the effectiveness of the AH-64 FWS as a training tool will depend on how accurately the cockpit instruments reproduce the information that the cockpit instruments in an operational AH-64 helicopter would present to the pilot and gunner while performing the same tasks. Not only must the AH-64 FWS instruments present accurate readings but they must accurately reproduce rates of change and time lags.

It is anticipated that the AH-64 FWS will be the primary locus of pilot training related to aircraft operation and control tasks. As such it will be in operation from 8 to 16 hours per day. Thus the accumulation of operating time on the instruments in the AH-64 FWS will be many times greater than for instruments in an operational AH-64 helicopter. Operational helicopter instruments, therefore, may not have adequate reliability or adequate useful life, or may require excess maintenance for use in the AH-64 FWS. However, some operational instruments are very complex and thus very expensive to simulate. Tradeoffs must therefore be made in choosing to use operational aircraft instruments, modified operational aircraft instruments, or simulated instruments.

The rationale for selecting instruments must be based on maximizing the availability of the AH-64 FWS for training, providing the specified performance, and minimizing the life cycle cost of the instrument. Certain instruments such as the barometric altimeter are pressure operated in the aircraft. All instruments falling in this category must be simulated using front faces and pointers from operational instruments. Other instruments, such as the all-attitude indicators and bearing, distance, heading indicators, are very complex and thus very expensive to simulate. Repair parts for a simulated instrument would be expensive and repair very difficult. In these instances trainer availability would be improved by using operational instruments for which spare parts and

repair facilities already exist. Operational instruments in the category of hydraulic pressure indicators, fuel quantity indicators, temperature indicators, etc., have mean-time-between-failure values that adversely affect trainer availability. Also various types of drive signals are needed to drive them. These instruments should be simulated in the AH-64 FWS.

To minimize simulator computer and interface hardware complexity, all instruments, whether operational or simulated, should be of the following types:

1. D.C. meter movement driven directly by the computer interface analog outputs.
2. D.C. servomechanisms with self contained amplifiers driven by the computer interface analog outputs.
3. 400 Hz synchros driven by solid state digital-to-synchro converters in the interface.

Meter movement type aircraft instruments should be simulated in AH-64 FWS as D.C. meter movement instruments. Those instruments requiring the movement of significant mass or activation of internal switches should be simulated by D.C. servomechanisms. All other instruments which cannot be simulated with D.C. meter movement or D.C. servomechanisms should be 400 Hz synchros.

The overall design for simulation of displays, lights, and control panels in the cockpit module should provide system operation identical to that within the AH-64 helicopter, as well as providing enhanced reliability, maintainability, and availability features. All switches and operable controls should have the same appearance and feel as the comparable item in the operational aircraft. All lights and light plates should have the same appearance, intensity, and control features as the comparable item in the operational aircraft. Experience has indicated that the mean time between failure for operational aircraft control panels consisting of switches and lights would not degrade the reliability of a simulator. Accordingly the rationale for selecting operational or

simulated panels of this type should be based on cost and availability. Certain control panels such as radio control heads are complicated and costly to simulate. Since they are extensively used in various aircraft the cost and availability of operational aircraft panels is advantageous. In these instances operational aircraft equipment should be used. Many of the control panels used in a simulator require wiring changes to operational aircraft panels to provide necessary signals to the computer. All such control panels should be simulated.

In order to provide availability of spares without special handling and special repair facilities, all operational aircraft instruments, indicators, and control panels that must be modified for use in the AH-64 FWS should be designed and provisioned as simulated parts. When operational aircraft parts are used in the AH-64 FWS they should be identified by the aircraft part number and should be tested and certified as being qualified for use in operational aircraft. All simulated instruments, indicators, and control panels including modified operational aircraft parts should be designed and provisioned so that all repairs can be accomplished at the trainer site by trainer maintenance technicians.

Recommendations

It is recommended that all instruments, indicators, and control panels in the AH-64 FWS be either operational aircraft parts or simulated parts. All simulated instruments, indicators, and control panels should have the same appearance, and should function the same as the counterpart in an operational AH-64 helicopter. Instruments should reproduce all rates of change and time lags, and should display no jitter or other anomalous operation when compared to the counterpart instrument in an operational AH-64 helicopter performing identical maneuvers. All operational instruments, indicators, and control panels used in the AH-64 FWS should be identified by the aircraft part number and should be

tested and certified to be acceptable for use in operational aircraft.

Both operational and simulated instruments used in the AH-64 FWS should be simulated by one of the following methods:

1. D.C. meter movements driven by analog outputs from the interface.
2. D.C. servomechanisms driven by analog outputs from the interface.
3. 400 Hz synchros driven by solid state digital-to-synchro converters in the interface.

The order of selection should be D.C. meter movements first and D.C. servomechanisms second. 400 Hz synchros should be used only when required. All D.C. servomechanism instruments should have self-contained amplifiers. To the grestest extent possible all simulated instruments should use interchangeable movements, motors, potentiometers, and amplifiers.

The design of all instruments and indicators should maximize simulator availability and reliability. All simulated parts should be designed to be repaired and maintained by the AH-64 FWS maintenance technicians at the trainer site.

MOTION SYSTEM MODULE

Aircraft Operational Motions

The aircraft motions to be simulated include those due to taxiing, in-flight maneuvering, atmospheric turbulence, weapons release and firing, powerplant, rotor and equipment operation, and aerodynamic buffet.

These motions may be grouped into two broad catagories: (1) low-frequency motions due to taxiing, in-flight maneuvering, and atmospheric turbulence, and (2) high-frequency motions and jolts due to weapons release and firing, powerplant, rotor and equipment operation, and aerodynamic buffet.

The low-frequency motions of the first category are motions involving accelerations up to approximately 3.0 g's and frequencies up to approximately 2.0 Hz which are associated with the vast majority of routine flight maneuvers in an attack helicopter. Table III of AMC-SS-AAH-H10000A, which is included in this report as Table 1, indicates that approximately 82% of the total YAH-64 maneuver spectrum is composed of maneuvers involving peak $N_{Z_{C.G.}}$'s between 0.75 and 1.25, and that approximately 92% of the maneuver spectrum is composed of maneuvers involving peak $N_{Z_{C.G.}}$'s between 0.50 and 1.50. These are the motions associated with the basic helicopter flying qualities and aerodynamic response, therefore it is essential that these basic motions be simulated in the AAH Full-Mission trainer.

The high-frequency motions and jolts of the second category involve impulsive accelerations and disturbance frequencies of approximately 2.0 Hz and higher. It is important that these motions be simulated in both the AAH Full-Mission Trainer and the separate CPG Trainer.

Motion System Requirements

The general requirements for motion simulation, as related to training effectiveness, are developed and discussed in Section II of this study report. The extent of motion simulation, i.e., the number of degrees of freedom of motion required for effective training, however, can not be determined through a consensus of the literature surveyed in that section. Therefore, in order to arrive at a recommendation for this requirement, Sperry SECOR surveyed helicopter-trainer user personnel at Fort Rucker, Alabama, and Fort Knox, Kentucky. Without exception, all instructors and pilots surveyed indicated a strong preference for six degrees of freedom of motion simulation in helicopter trainers. This preference among the trainer user personnel is deemed sufficient to justify a recommendation for six degrees of freedom of motion,

Table 1

YAH-64 Maneuver Spectrum

Peak Nz at c.g.	Time at g (sec)	Cumulative Exceedances per 4500 hrs.
3.00	0.8	200
2.75	1.2	500
2.50	1.7	1,000
2.25	2.8	2,000
2.00	4.0	5,000
1.75	6.0	10,000
1.50	10.0	20,000
1.25	12.0	150,000
0.75	4.2	60,000
0.50	2.8	8,000
0.25	2.5	1,000
0	2.0	200

Reference:
AMC-SS-AAH-H10000A
15 October 1976
Page 1-289

particularly in view of the lack of any clear consensus on the subject in the technical literature.

Due to the constraints imposed by the visual-system-related requirement to maintain the trainee station excursions within a relatively small space about the projection screen focal point, the motion excursion requirements for the AAH Mission Trainer are well within the limits of capability of standard state-of-the-art motion systems. The objective, then, is to determine the most cost-effective approach for generating the required six degrees of freedom of motion simulation.

One approach for providing six-degrees-of-freedom motion is the utilization of a cascaded motion system. This approach was investigated utilizing as a starting point Sperry SECOR's three-degree-of-freedom cascaded motion system, which is described in Figures 3, 4 and 5, and estimating the additional cost involved in modifying the system to provide six degrees of freedom, increased vertical excursion capability, and a payload capability of 6000 pounds. This investigation revealed that the overall development, hardware and labor costs for this approach would roughly equal the cost of developing or procuring a standard six-degree-of-freedom synergistic motion system.

Based on these results, it is concluded that a standard six-degree-of-freedom synergistic motion system would provide the most cost-effective alternative for meeting the desired motion simulation requirements established for the AAH Full-Mission Trainer. This type of motion system also provides increased cost effectiveness due to the standardization of actuators, servovalves and other components, thereby reducing provisioning and maintenance requirements.

It is estimated that the weight of the AAH Mission Trainer cockpit would be approximately 3000 pounds, and that an on-board instructor's station, if required, would add another 2000 pounds.

SPERRY SECOR THREE-DEGREE-OF-FREEDOM MOTION SYSTEM

The Sperry SECOR motion system is a standard three-degree-of-freedom system that provides motion in roll, pitch, and heave. This motion system was produced and delivered as a part of two A-4M flight trainers, two A-4H flight trainers, two A-4N flight trainers, and one A-4KU flight trainer. These systems have proven very effective in providing cues of acceleration and attitude changes in vertical translation, pitch attitude and roll attitude. Due to superior response characteristics, the Sperry SECOR three-degree-of-freedom system is particularly effective in providing motion simulation for high performance attack and fighter type flight simulators.

Each of the three motions are independent of the others. Thus, the amplitude of one degree of freedom is not limited by the instantaneous position of the other degrees of freedom. Also, since the computation of the motion of one actuator is independent of the other two, the motion system program module is very short and does not have the complexity of a program for a synergistic system where every motion requires the calculation of an input to all six actuators.

Another feature of the Sperry SECOR three-degree-of-freedom motion system design is that all hydraulic actuators are close coupled with very small trapped hydraulic fluid volume. Thus, the response time is low, thereby providing excellent frequency response and accurate coordination with the trainer G-suit and visual system.

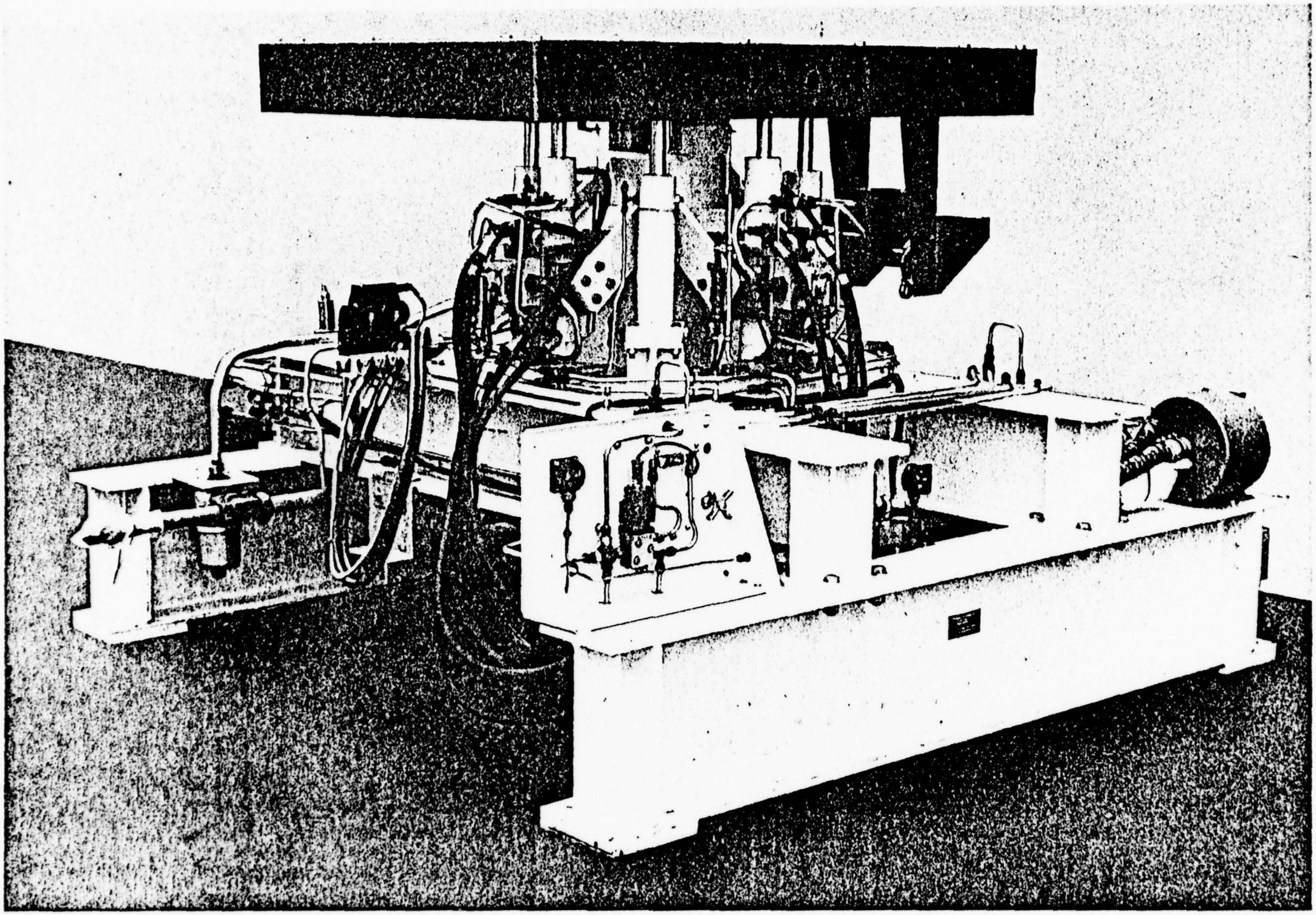
The Sperry SECOR motion system is an electro-hydraulically actuated servomechanism which provides the following displacements, velocities, and accelerations:

Motion	Max. Excursion	Max. Velocity	Max. Acceleration
Heave	±6 Inches	±20 In/Sec	±.9 G
Roll	±15 Degrees	±30 Deg/Sec	±50 Deg/Sec^2
Pitch	±15 Degrees	±30 Deg/Sec	±50 Deg/Sec^2

The motion system meets the time response and frequency response requirements of MIL-STD-1558.

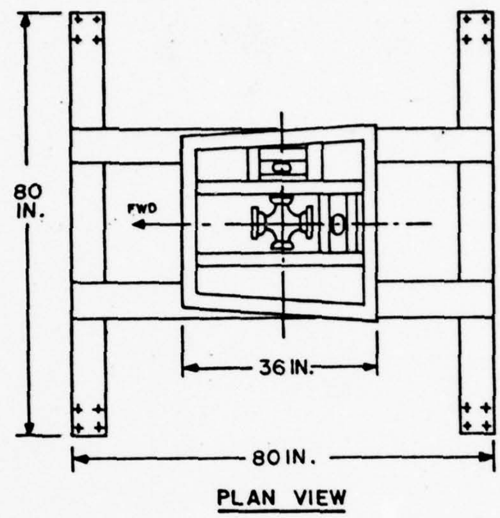
The design payload capability of the Sperry SECOR three degree of freedom motion system is 2000 pounds. The payload capability may be increased to 3400 pounds through the incorporation of minor modifications which have been identified in a preliminary engineering analysis.

Figure 3. Sperry SECOR Three-Degree-of-Freedom Motion System



Sperry Secor Three DOF Motion System

Figure 4



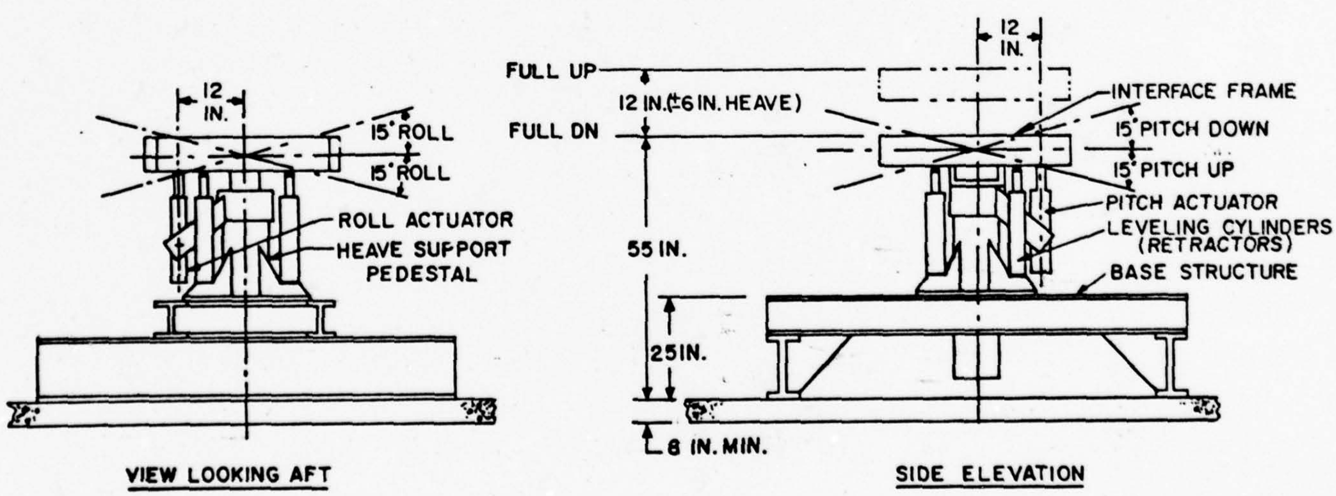


Figure 5. Sperry SECOR Three-Degree-of-Freedom Motion System

Thus, the total payload requirement for the motion system will be approximately 5000 pounds, which is well within the capability of state-of-the-art synergistic motion systems.

Sperry SECOR's approach for satisfying the AAH Trainer motion system requirements developed in this section would be to design and develop a six-post six-degree-of-freedom synergistic motion system as described below.

Motion System Description

The Sperry SECOR motion system recommended for the AH-64 FWS would be a standard six-leg six-degree-of-freedom synergistic system which would provide motion consisting of pitch, roll, yaw, heave, lateral, and longitudinal components. The physical movement of the motion system would be determined by computations based upon six degrees of aircraft freedom. The simulated motions would optimize the tracking of the total acceleration vector of the simulated aircraft including changes in magnitude and direction. The motion system would follow the aircraft dynamic motion subject to an attenuation function and a washout function which is below the threshold of perception of the training crew members. The motion system would be controlled so as to respond to aircraft center-of-gravity movement, center-of-pressure movement, fuel depletion, internal and external cargo loading, variable aerodynamic effects, and progressive malfunctions. Also, the motion system would be controlled so that the cockpit would maintain a relative pitch attitude corresponding to the steady-state simulated aircraft pitch attitude. The motion system would be designed to operate with minimal hunting and with no snubbing against cushion stops during normal operation.

The motion system servoactuators would be manufactured to Sperry SECOR specifications. The actuator stroke would be 50 inches, which would provide ±30 inches of actuator travel about the neutral position. The piston diameter would be 3.50 inches and the rod diameter 2.50 inches. This would provide a ram having a two-to-one

ratio between the head-end effective piston area and the rod-end effective piston area. The areas thus would be 9.621 square inches for the head end and 4.908 square inches for the rod end. System pressure would be maintained at a value that would produce an actuator rod buckling factor-of-safety of approximately 10. Dual 252.25 series MOOG/MTS servovalves would be used to control hydraulic fluid flow to each actuator. LVDT position transducers, tachometers, and P transducers would furnish feedback signals for the servovalve control loops.

The motion platform, to which the payload would be attached, would be supported by six identical servoactuators arranged in three bipod pairs. The actuators would be connected to the motion platform and the motion base assemblies by pin-and-clevis joints.

Figure 6 shows the general arrangement of the motion system. Major dimensions are included.

Figures 7 through 11 show the maximum excursions of the motion system in each degree of freedom.

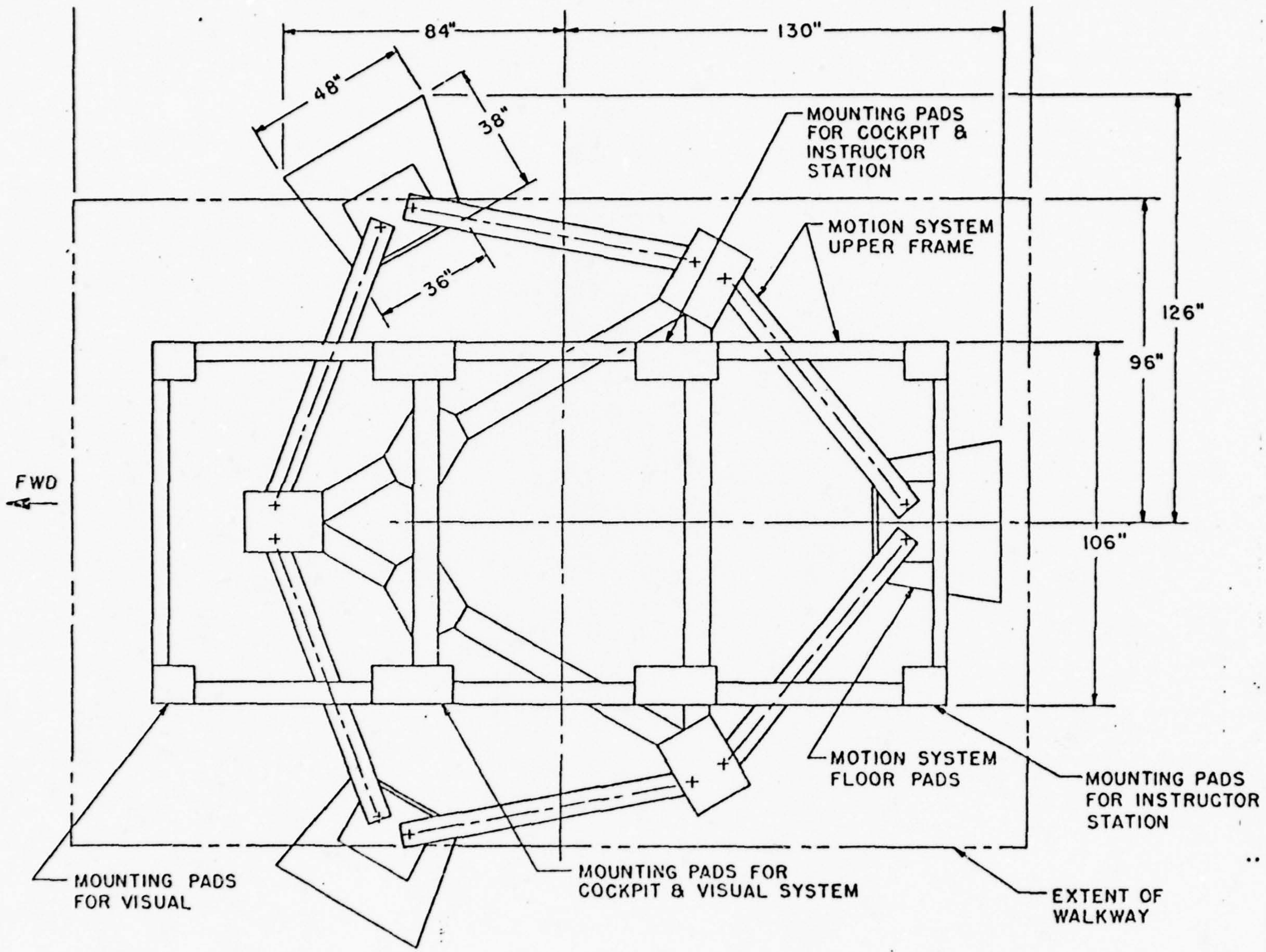
<u>Payload</u>

The motion system payload capability would be 15,000 pounds.

All load-carrying structural members would be sized to provide a minimum safety factor of four times yield strength under simultaneous conditions of worst-case configuration and worst-case dynamic loads associated with the 15,000 pound payload. A proof load test would be performed to verify the structural integrity of the motion system.

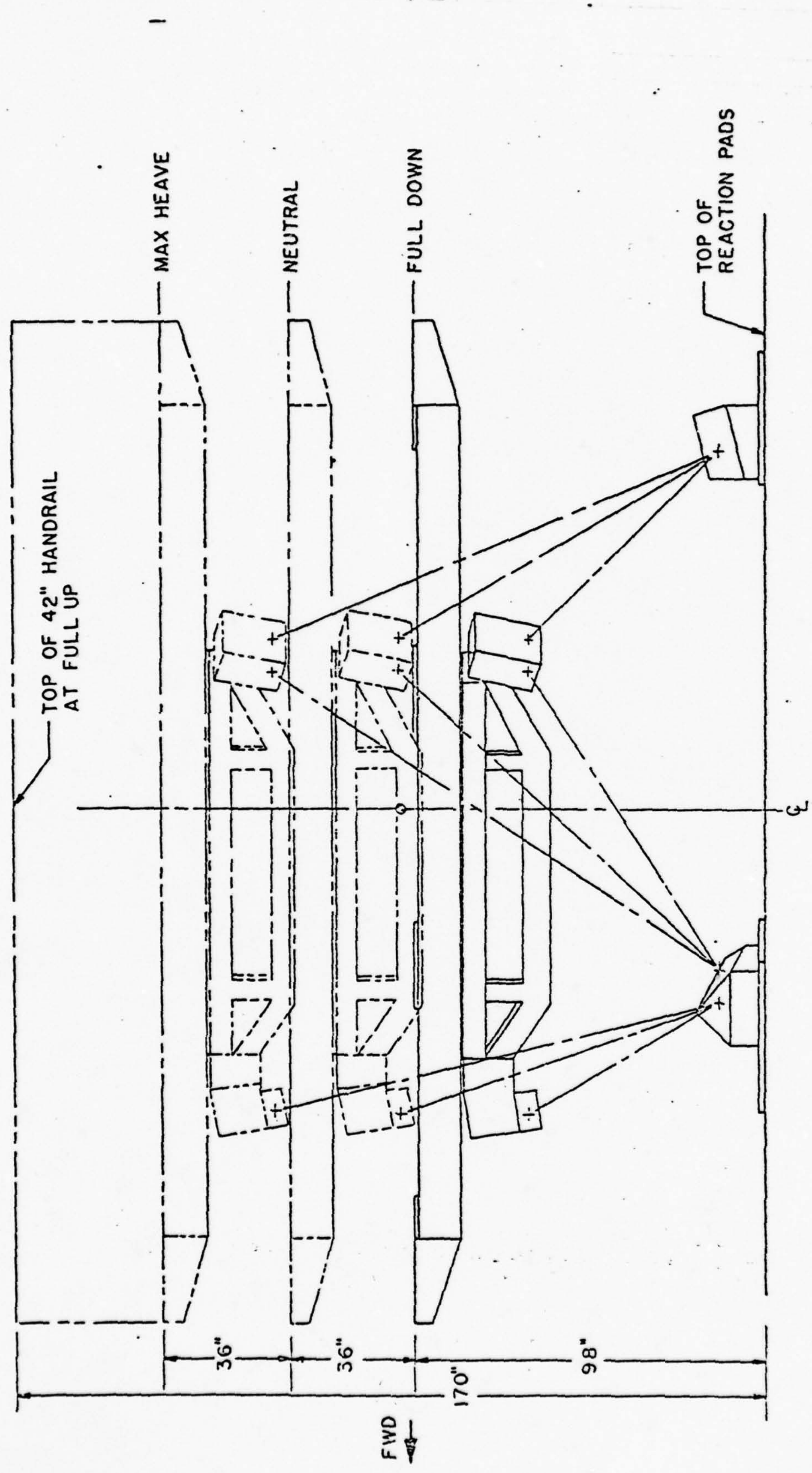
<u>Excursions, Velocities and Accelerations</u>

The motion system excursion, velocity, and acceleration capabilities in each degree of freedom should be as follows:



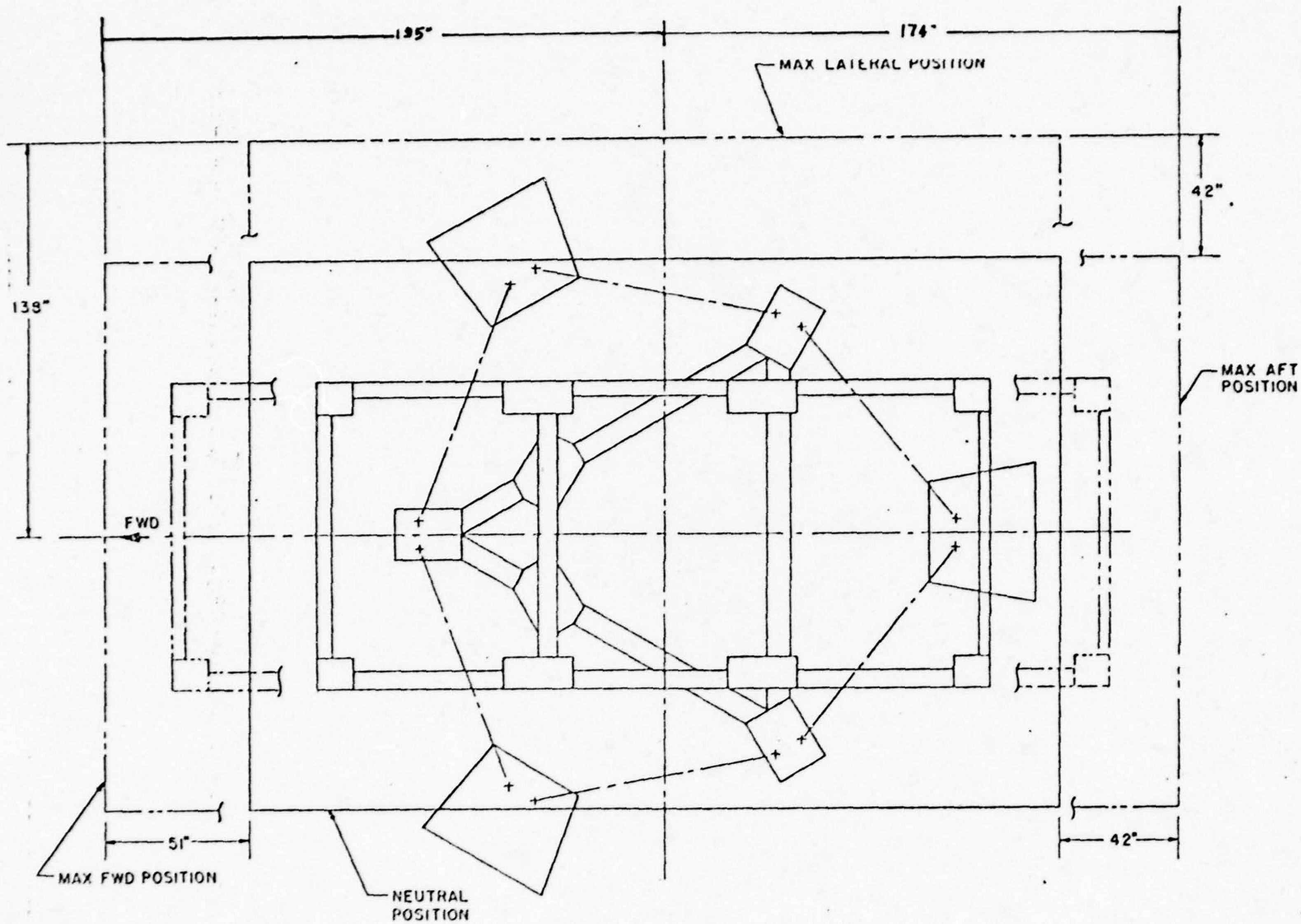
MOTION SYSTEM GENERAL ARRANGEMENT

Figure 6



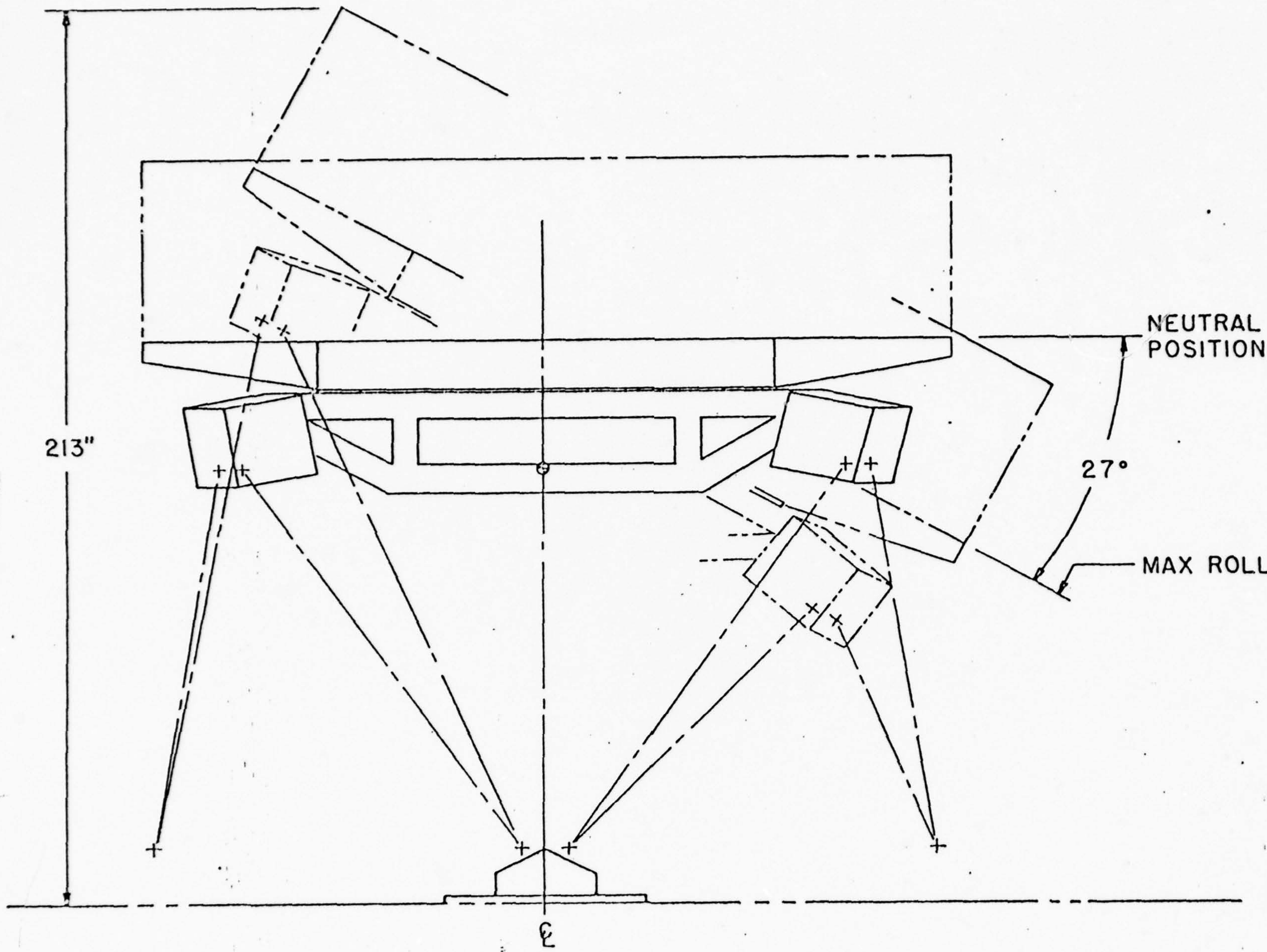
MOTION SYSTEM HEAVE LIMITS

Figure 7



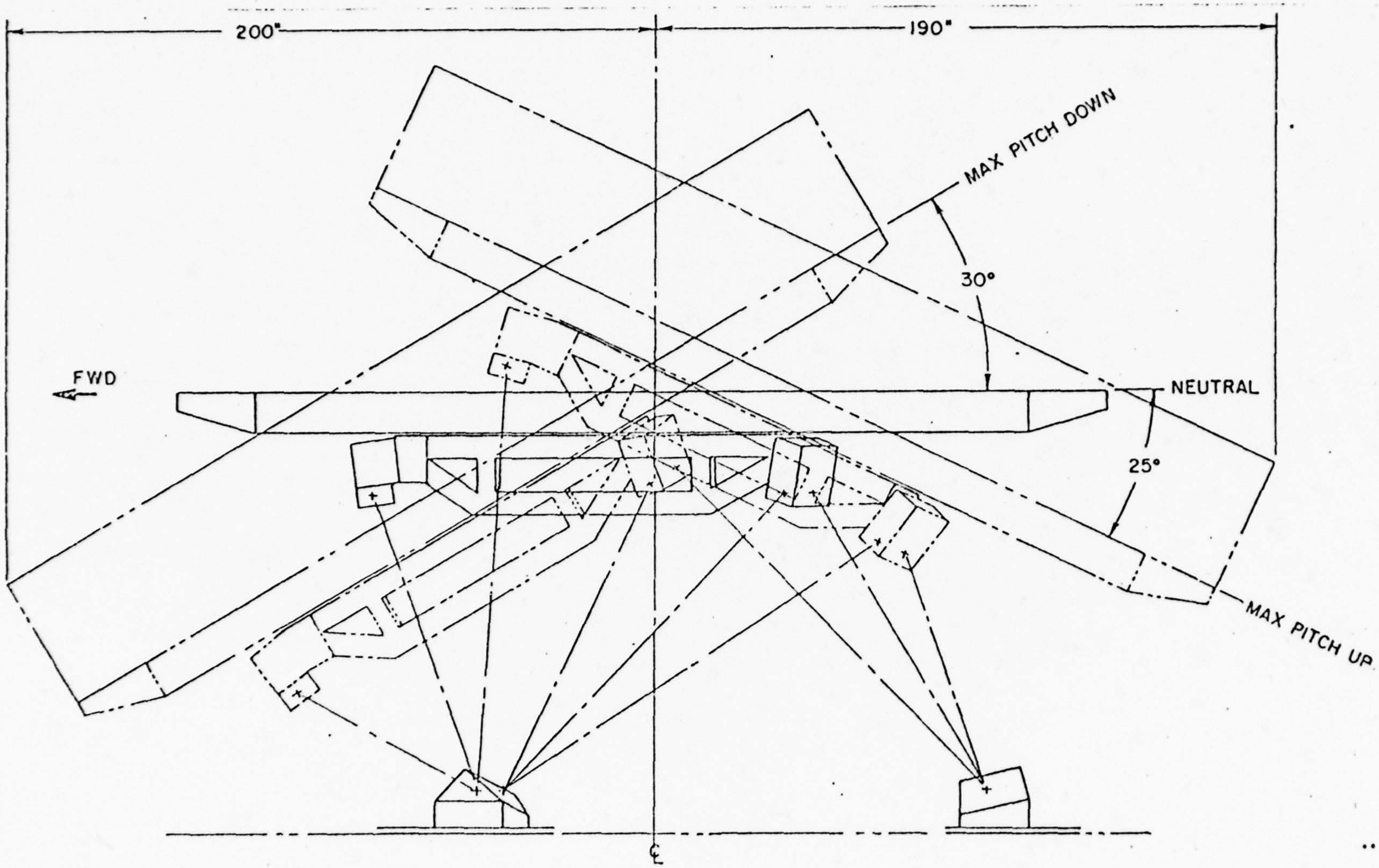
MOTION SYSTEM
LATERAL AND LONGITUDINAL LIMITS

Figure 8



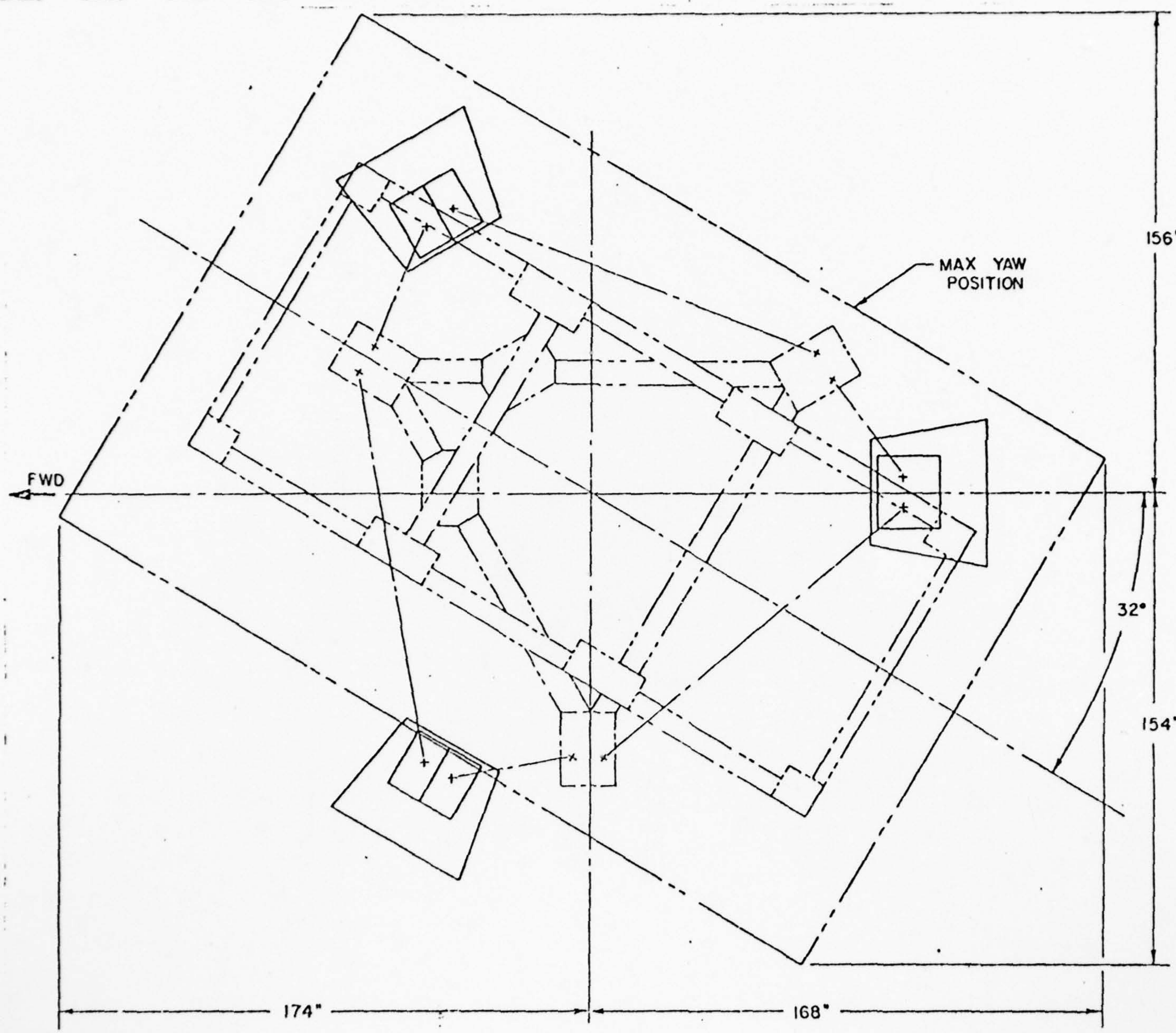
MOTION SYSTEM ROLL LIMITS

Figure 9



MOTION SYSTEM PITCH LIMITS

Figure 10



MOTION SYSTEM YAW LIMITS

Figure 11

		Maximum Capability	Reduced for AAHT
Pitch	Excursion	+30° -25°	±15°
	Velocity	±20°/SEC	
	Acceleration	$\pm 100°/SEC^2$	
	Acceleration Onset	$\pm 300°/SEC^2/SEC$	
Roll	Excursion	±27°	±15°
	Velocity	±23°/SEC	
	Acceleration	±100°/SEC	
	Acceleration Onset	$\pm 300°/SEC^2/SEC$	
Yaw	Excursion	±32°	±15°
	Velocity	±24°/SEC	
	Acceleration	$\pm 100°/SEC^2$	
	Acceleration Onset	$\pm 300°/SEC^2/SEC$	
Vertical	Excursion	±36 IN.	±12 IN.
	Velocity	±29 IN./SEC	
	Acceleration	±.8 g	
	Acceleration Onset	±5 g/SEC	
Lateral	Excursion	±42 IN.	±12 IN.
	Velocity	±34 IN./SEC	
	Acceleration	±.7 g	
	Acceleration Onset	±3 g/SEC	
Longitudinal	Excursion	+51 IN. -42 IN.	±12 IN.
	Velocity	±33 IN./SEC	
	Acceleration	±.7 g	
	Acceleration Onset	±3 g/SEC	

Motion System Safety Provisions

The motion system should be provided with an emergency cut-off control that can be operated from the inside or the outside of the flight compartment. A master maintenance control should be provided to ensure that the motion system can be deactivated when maintenance personnel are inside the motion structure. The motion

safety system should consist of hydraulic, mechanical and electronic subsystems each capable of operating irrespective of the status of the other.

The hydraulic safety system should include the following features:

- Fail-safe geometry to prevent an unsafe condition under any combination of actuator travels.
- Progressively smooth throttling of oil flows as limits of motion are approached. The energy-absorption capacity will be adequate to handle a runaway-actuator condition.
- Hydraulic cushions at travel limits.
- When the system is shut down, a control will be provided to dump system pressure to zero within one minute.

An electronic failure-detection system should be supplied which would detect system malfunctions and cause the motion system to return to the rest position. The conditions which would be detected by the electronic safety system are as follows:

- Travel limits exceeded. (Each hydraulic actuator should be provided with an electrical limit switch at each end. Activation of any one limit switch would cause the motion system to shut down).
- Provision for program not iterating (checks discrete output changing state at the nominal computer iteration rate).
- Excessive signal to servo valves, caused by amplifier failure.
- Provision for discrepancy in the digital-to-analog or analog-to-digital signal conversion.
- Operation of any EMER OFF switch.
- Low oil pressure - loss of system operating pressure.
- Loss of electrical power - loss of any voltage, including loss of power to the failure detection system, would cause the enabling valve to open. This would cause the motion platform to return to the rest position at a controlled rate.

It should not be possible to engage the motion system unless all interlocks are in a safe position. Operation of the instructor's switch when the interlocks are in an unsafe position should not cause the motion to go on even if the interlocks subsequently move to the safe position.

When any EMER OFF switch has been activated, the motion system should remain inoperable until the instructor initiates the normal control switch starting sequence, or until a reset is manually performed on the Maintenance Panel.

Indicator lights should be provided for the following:

- Manual Shut-Off - indicates that the motion system was shutoff by one of the EMER OFF switches.
- Out of Limits - indicates that an actuator has exceeded its travel limits and has activated a limit switch.
- Loss of Power - indicates loss of power to the motion system (light does not illuminate if power for light is lost, until power is restored).
- Low Oil Pressure - indicates the motion system pressure has dropped below a predetermined value.
- High Oil Temperature - indicates that the oil temperature has exceeded a certain predetermined value.
- Filter Pressure Differential - each of ten lights indicates a contaminated filter. The lights sense one filter on input to each jack, one in the cooling line, one in the case drain line, one in the system return line, and one in control force system.
- Fail-safe electrical interlocks - prevent activation of the motion system in an unsafe condition.

Aircraft-to-Motion-System Drive Equations

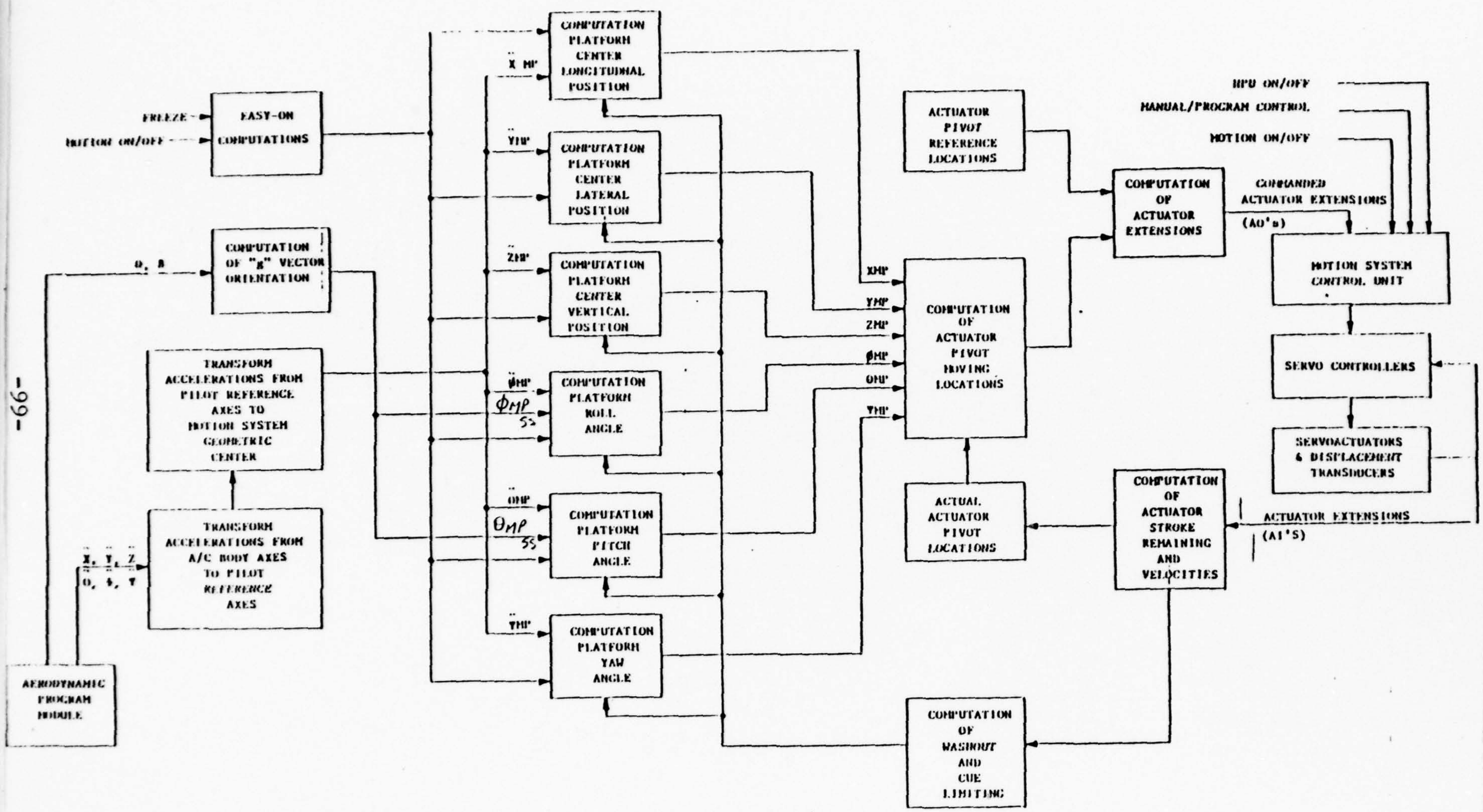
Motion system drive equations would generate the control signals required to simulate realistic aircraft accelerations, attitudes, and buffet motions in six degrees of freedom. The inputs would be the aerodynamic program module and the current position of the motion platform. The motion system program module would compute the desired accelerations and "g" vector orientation in six degrees of freedom with respect to the center of gravity and body axis of the aircraft. A coordinate transformation would then be made to compute the corresponding desired accelerations and "g" vector orientation at the geometric center of the motion system platform. Using this data, the motion system program module would then compute a new desired extension for each of the six

actuators. At the same time it would apply washout criteria, actuator velocity and limiting criteria, and platform easy-on criteria to compute the final actuator extension analog output to each servo valve amplifier.

Figure 12 is a block diagram of the motion system drive equations. Symbols are defined as follows:

$\ddot{X}$	Total Longitudinal Acceleration
$\ddot{Y}$	Total Lateral Acceleration
$\ddot{Z}$	Total Vertical Acceleration
$\ddot{\phi}$	Roll Acceleration
$\ddot{\theta}$	Pitch Acceleration
$\ddot{\Psi}$	Yaw Acceleration
θ	Pitch Angle
$\ddot{X}_{MP}$	Platform Longitudinal Acceleration
$\ddot{Y}_{MP}$	Platform Lateral Acceleration
$\ddot{Z}_{MP}$	Platform Vertical Acceleration
$\ddot{\phi}_{MP}$	Platform Roll Acceleration
$\ddot{\theta}_{MP}$	Platform Pitch Acceleration
$\ddot{\Psi}_{MP}$	Platform Yaw Acceleration
θ_{MP}	Platform Pitch Attitude

As shown, the inputs to the motion system program module would be aircraft accelerations in six degrees of freedom, aircraft pitch attitude, sideslip angle, freeze, and ON/OFF control. The program would first accept the six acceleration terms referenced to the aircraft center of gravity and body axis system and translate them to the pilot's reference location. These terms would then be translated from the pilot's reference location to an axis system fixed to the geometric center of the motion system upper frame.



BLOCK DIAGRAM

MOTION SYSTEM DRIVE PROGRAM AND CONTROL SYSTEM

Figure 12

Steady-state pitch attitude and sideslip angle from the aerodynamic program module would be used as the input to a computation of the "g" vector orientation. The output terms $\Theta_{MP_{SS}}$ and $\phi_{MP_{SS}}$ would represent motion system upper platform pitch and roll angles in the steady-state, or initial, condition.

Using as inputs platform accelerations, platform pitch and roll attitudes, washout and cue-limiting terms, and an easy-on term, the program would compute commanded motion system platform positions in the six degrees of freedom. A freeze command input would have priority control over this computation to return the platform to neutral position at slow rate. Motion ON or OFF command inputs would be possible only in the freeze mode. If these inputs are initiated when the trainer is out of freeze, the trainer would revert to freeze, proceed through the easy-on cycle, and remain in the freeze mode. The instructor would then be able to deselect FREEZE to place the trainer in operation. The computation of platform positions would include washout and cue-limiting terms. These terms would be computed from the instantaneous actuator velocities and stroke remaining. The washout term would constantly attempt to return the platform to a desired steady-state attitude at a subliminal rate. Cue limiting would limit the onset acceleration actuators prior to engaging the hydraulic stops.

The platform-position terms would then be used as inputs to a computation of commanded actuator extensions for each of the six actuators. These terms would be sent as analog outputs to the servo valve amplifiers.

Each actuator would have a position sensor to generate actuator position analog inputs. These terms would be used to compute the washout, cue limiting, and actual actuator pivot locations.

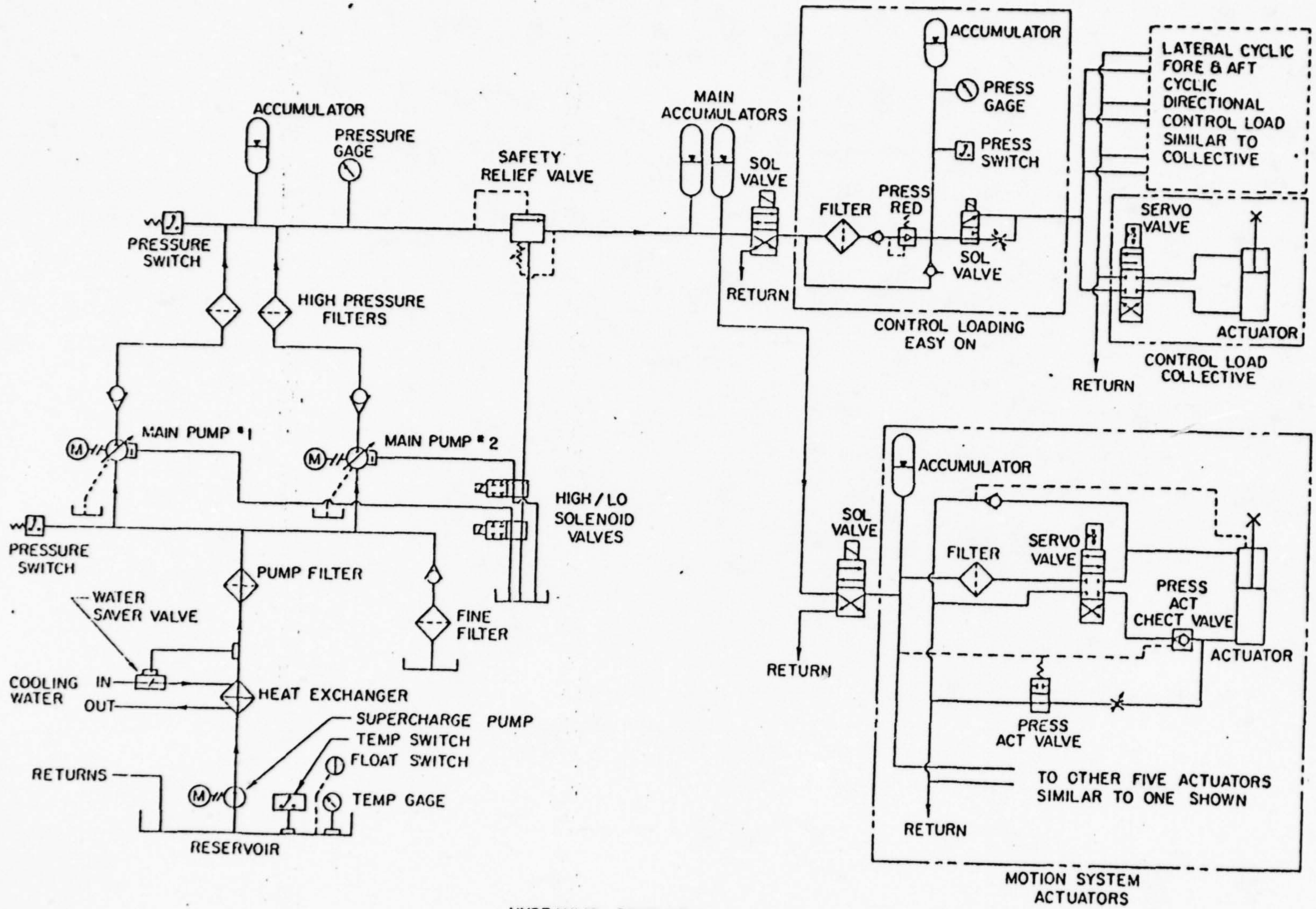
Hydraulic Power System

Figure 13 is a hydraulic schematic diagram of the recommended hydraulic power system and the motion system. The design incorporates an MTS System Corporation Model 506.81 hydraulic power supply. The rated capacity of this unit is 140 gallons per minute at an output pressure of 3000 psi. Some of the main features of this unit are:

- Energy-saving variable volume models pump only the fluid required. For additional power savings, operation of only one of the two pumps, when flow requirements permit.
- Water-conserving valve automatically controls cooling water flow to maintain proper hydraulic fluid temperature.
- Exceeds all JIC or OSHA standards for hydraulic equipment. Failsafe circuits automatically turn off the supply if an abnormal condition develops (fluid over temperature, low level, or pump motor thermal overload).
- HIGH-STOP-LOW functions controlled at the supply or via remote control panel allow safe start-up in low pressure and switching to high pressure.
- Pumps are rated for 3000 psi continuous duty and can be operated intermittently at up to 3500 psi.
- Filtration rated at 3 microns absolute which exceeds fluid conditioning requirements for reliable high-performance servovalve operation.

Hydraulic Power Unit

The hydraulic power unit has variable-volume (pressure-compensated) main pumps with a pressurized inlet (supercharge). A screw-type supercharge pump draws fluid from the reservoir and forces it through a heat exchanger and a relatively coarse main-pump inlet filter that removes contaminants large enough to cause rapid pump wear. Fluid not required by the main-pump inlet returns to the reservoir through a 3-micron fine filter. A pressure switch on the supercharge line protects the main pump by turning it off if pressure drops below a safe level. Supercharge fluid passes over heat-exchanger tubes that contain cooling water. Cooling water flow is automatically varied by an adjustable water-saver valve which has its sensor immersed in fluid.



HYDRAULIC SCHEMATIC

Figure 13

Since output flow varies automatically with external circuit demand, the main pressure control is on the main pump. No fluid is bypassed to maintain high output pressure but an adjustable safety relief valve will limit output pressure should the main pressure control malfunction. Output fluid is pumped through a check valve and then through a 10 micron high pressure filter to the external circuit.

The safety relief valve also has a vent port that is connected through a high/low solenoid valve to provide a low pressure condition. With the high/low solenoid valve energized, the safety relief valve vent is blocked and system pressure can rise to high pressure. With the high/low solenoid valve de-energized, the vent is opened, high pressure fluid is dumped to the reservoir, and output pressure falls to a low level. The low pressure conditions occurs: (1) automatically whenever the main pump motor is shut off (including electrical power failure and detection of an abnormal condition), (2) during supply turn-on for "soft start", (3) when the operator selects low pressure for low force, low velocity actuator positioning.

The accumulator has two functions. It reduces small pressure fluctuations by storing and releasing pressurized fluid. The larger accumulator allows use of servovalves having flows higher than the rating of the hydraulic supply, the difference in short-term peak flow being made up by the accumulator.

A control on the panel allows operation of one or both pumps as required. Also, the main pump vent ports are connected to the high/low solenoid valve so that, with one pump running, the second pump can be started in its low pressure condition.

Control Loading Hydraulic Supply

As shown on the hydraulic schematic, Figure 13, the control loading units would be supplied with hydraulic power from the

hydraulic power supply unit through a solenoid control valve and easy-on unit. The solenoid valves for both the control loading and the motion system should be individually controllable. This would allow the control loading to be operated without the motion system. Also, in case of failure of one of the main pumps, the controls loading would be operated from the other pump.

The easy-on system would consist of a filter, pressure reducing valve, accumulator, and three-way solenoid valve. The pressure-reducing valve reduces the primary pressure down to 1200 psi for use in the control loading. When pressure is first applied to the system, the supply of fluid to the control loading is directed through the three way solenoid valve and adjustable restrictor valve to the servo valves. The volume of fluid passed by the restrictor allows only very slow movement of the controls. A ten-second time delay relay controlled by the pressure switch shifts the three-way solenoid valve to place full flow to the servo valves. At any time hydraulic power or electrical power is interrupted, the easy-on is automatically recycled. The easy-on assembly represented by the schematic has been used on all the A-4, H-3, H-52 and H-53 trainers previously designed by Sperry SECOR.

<u>Motion System Actuators</u>

Figure 13 ahows a simplified hydraulic schematic for the motion system actuators. As shown, hydraulic fluid would be supplied to the six motion system actuators through a solenoid valve. The schematic diagram represents one of the six actuators. The other five actuators would be identical. As shown in Figure 13, each actuator would have an accumulator and high pressure filter in the supply line to the servo valve.

To prevent the motion platform from descending at an excessive speed in case of sudden loss of hydraulic pressure, an automatic easy-down hydraulic circuit should be included on each actuator. This circuit would consist of a pressure-actuated check valve in

the line from the servo valve to the head end of each actuator. This would prevent the motion platform from descending if the supply pressure becomes too low for servo valve control. At the same time the pressure-actuated check valve closes a pressure-actuated bypass valve and adjustable restrictor valve would allow a controlled rate of descent of the motion platform.

G-Seat Requirements

Motion systems, owing to their mechanical constraints, produce the most useful stimuli, or cues, during the onset phase of low-level short-term accelerations. However, as the accelerations to be simulated become larger in magnitude and/or longer in duration, the capabilities of the motion system are approached and cue generation is constrained or terminated.

G-seats provide a useful method for partially simulating sustained high-g accelerations. The effect of the g-seat is to complement the motion system in the sustained and/or high-g motion regime.

G-seat technology has advanced sufficiently to justify technical confidence in the concept, utilizing either pneumatic or hydraulic operating principles. Sperry SECOR has generated preliminary designs for both types of systems and will soon initiate a hardware development program aimed at design optimization, testing, and evaluation.

Since the technology is therefore available to provide a g-seat system, the primary objective of this section is to determine the requirement for utilizing this system in the AAH Trainer. The primary aspect of the requirement to be evaluated is, of course, the necessity for simulating sustained high-g accelerations. This requirement hinges on the training requirements and effectiveness criteria discussed in Section II of this Study Report.

Since the low-frequency flight motion simulation requirements developed in Section II do not include sustained high-g acceleration simulation, it is concluded that a g-seat system will not be required for the AAH Trainer. This conclusion is, of course, consistent with the study objective of defining the most cost effective AAH Trainer configuration, since a complex and expensive system is thus eliminated from the trainer configuration.

Vibration-and-Buffet System Requirements

The high-frequency motions and jolts, described as disturbance motions in Section II, are motions that should be simulated in both the AAH Full-Mission Trainer and the separate CPG Trainer. In the Full-Mission Trainer these motions can be simulated either by the basic motion system or by a seat shaker, and in the CPG Trainer by a vibration-and-buffet system.

In the interest of simplicity and better fidelity, Sperry SECOR recommends that a seat shaker be installed in the Full-Mission Trainer. Sperry SECOR's experience is that it is difficult to obtain high frequency motions with the basic motion system, and that a seat shaker adequately simulates such motions at less overall cost and better reliability.

For the CPG Trainer a vibration-and-buffet system could be mechanized as either a cockpit shaker or a seat shaker.

The cockpit-shaker approach would provide practically total fidelity of high-frequency random-motion simulation. The system would be mechanized to include two degrees of freedom of motion: lateral translation and vertical translation.

It would be hydraulically operated and electrically controlled in response to computer-generated commands. This would allow for simulation of various disturbance spectra which would be stored in the computer program and outputted to drive the cockpit shaker in response to the total system simulation.

In the alternative approach, the seat shaker would be identical to that in the Full-Mission Trainer. It would be substantially less expensive than the cockpit shaker.

In order to minimize costs Sperry SECOR recommends that the seat shaker be used in the CPG Trainer.

Facility Considerations

The AAH Trainer concept described in this report will require the following approximate facility dimensions:

	EQUIPMENT AREA				
	TRAINEE-MT	TRAINEE-NWST	COMPUTER	INSTRUCTOR	UTILITY
FLOOR SPACE (feet)	60X40	30X20	30X20	20X20	12X12
CEILING HEIGHT (feet)	33	10	10	10	10

A 12' X 12' door should be provided in the facility building to allow passage of trainer components.

The ceiling, floor, and walls of the Trainee Area should be finished with flat black paint to reduce extraneous light reflection and thus enhance the effectiveness of the visual system. Particular attention should be paid to avoiding the presence of protruding objects, such as pipes or switch boxes, behind the screen. Such objects, even though painted black, could catch the student's eye and prove distracting.

Power requirements will not be unusual. Since a terrain model board visual system is not recommended, the high power requirements associated with that type of system, if incandescent lights are used, will be avoided.

VISUAL SYSTEM MODULE

Introduction

This section of the study will address the components and technology of the visual system module.

It should be clear at the outset that the modules comprising the trainer are interdependent, so that selection of a specific configuration of one may dictate limitations or even elimination of others. In the visual system module area, for example, selection of a virtual image type display for the pilot and copilot/gunner (CPG) windscreen view dictates a two-cockpit configuration for the cockpit module. Also, selection of a motion system module may limit the choice of display techniques and even eliminate some available display hardware from consideration.

The visual subsystem includes all aspects of image generation and display to the pilot or copilot/gunner, for any purpose. Thus, it includes not only the scene observed through the cockpit windows, but the pilot's and CPG's view (as applicable) through the Pilot's Night Vision Sight (PNVS), the Target Acquisition and Designation System (TADS) sensors, displayed on the Integrated Helmet and Display Sight System (IHADSS) and the gunner's panel displays.

In an earlier section of this study, specific training tasks were examined for the general applicability of model-board computer image generation, and film visual image techniques. Let us examine some of these tasks to derive more specific technical requirements of a visual system.

A key area is training for the terrain flight modes (NOE, low level, contour) plus landing and takeoff regimes. In daylight visual conditions, expected to obtain for 75-80% of all missions, the pilot and the CPG observe the scene through the cockpit windows.

Field of View

A major characteristic of these flight modes is their visual field of view. Figures 14 and 15, following, show the fields provided by the aircraft windows. As can be seen, the CPG, because of his forward position in the aircraft, has a somewhat more extensive field of view than the pilot.

Some study work has already been published by the Army as to what fields of view are required by the pilot to accomplish his piloting tasks in the AAH.* Figure 16 shows the results of these on the same scale as the pilot's vision plot of the YAH-64. As can be seen, the pilot is limited to about ± 125° in azimuth and can see down to the desired -30°, although not directly ahead. His upward view is extensive except for windshield mullion blockage. He can see well beyond the desired +30° for taxi, takeoff and landing, and the desired +45° for NOE flight. In the actual aircraft, his view grows toward 180° at his zenith, but this area is not utilized for these tasks.

In discussion of field of view with Cobra instructor pilots who had combat experience, the importance of maximum possible depression angle was emphasized. In contrast with the Fig. 16 plot, they deemphasized the elevation view, with 10-15° being considered quite adequate. During a flight in the front seat of the Cobra, it was clear that it was nearly impossible to twist the body while in the shoulder harness/safety belt to see beyond ± 90° in azimuth. Thus it appears that a realistic field of view for the simulator would provide the maximum depression angle that either crewman is capable of seeing, which Figs. 14 and 15 show to be -40°, and +15° elevation angle, for a total of 55° vertical angle. Azimuth angle should match the ± 90 which can be comfortably seen from the cockpit, for a total of 180° horizontal angle.

*Army 5 Year Plan, Appendix D, pg D-3

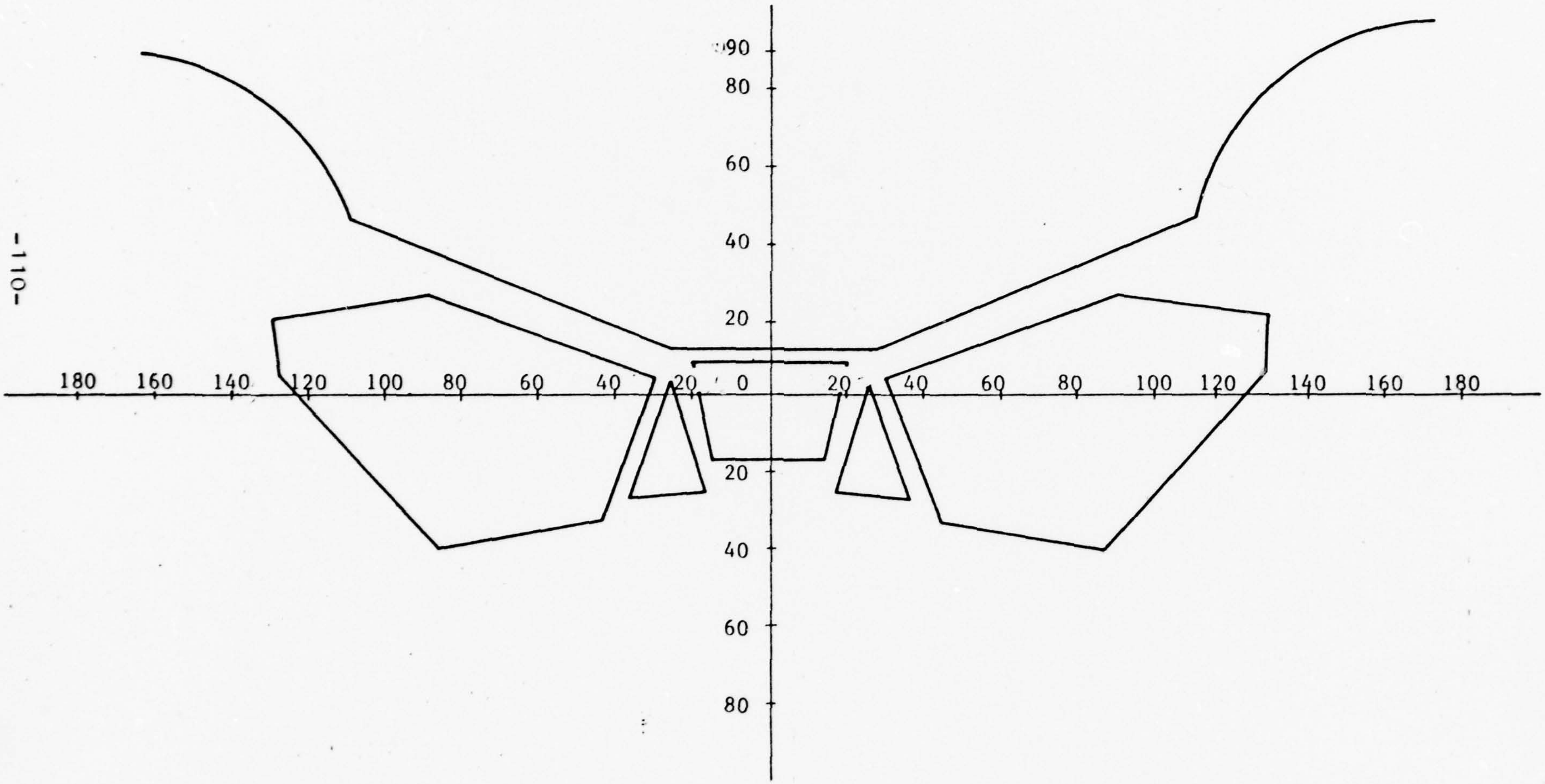


Figure 14
AAH PILOT VISION PLOT

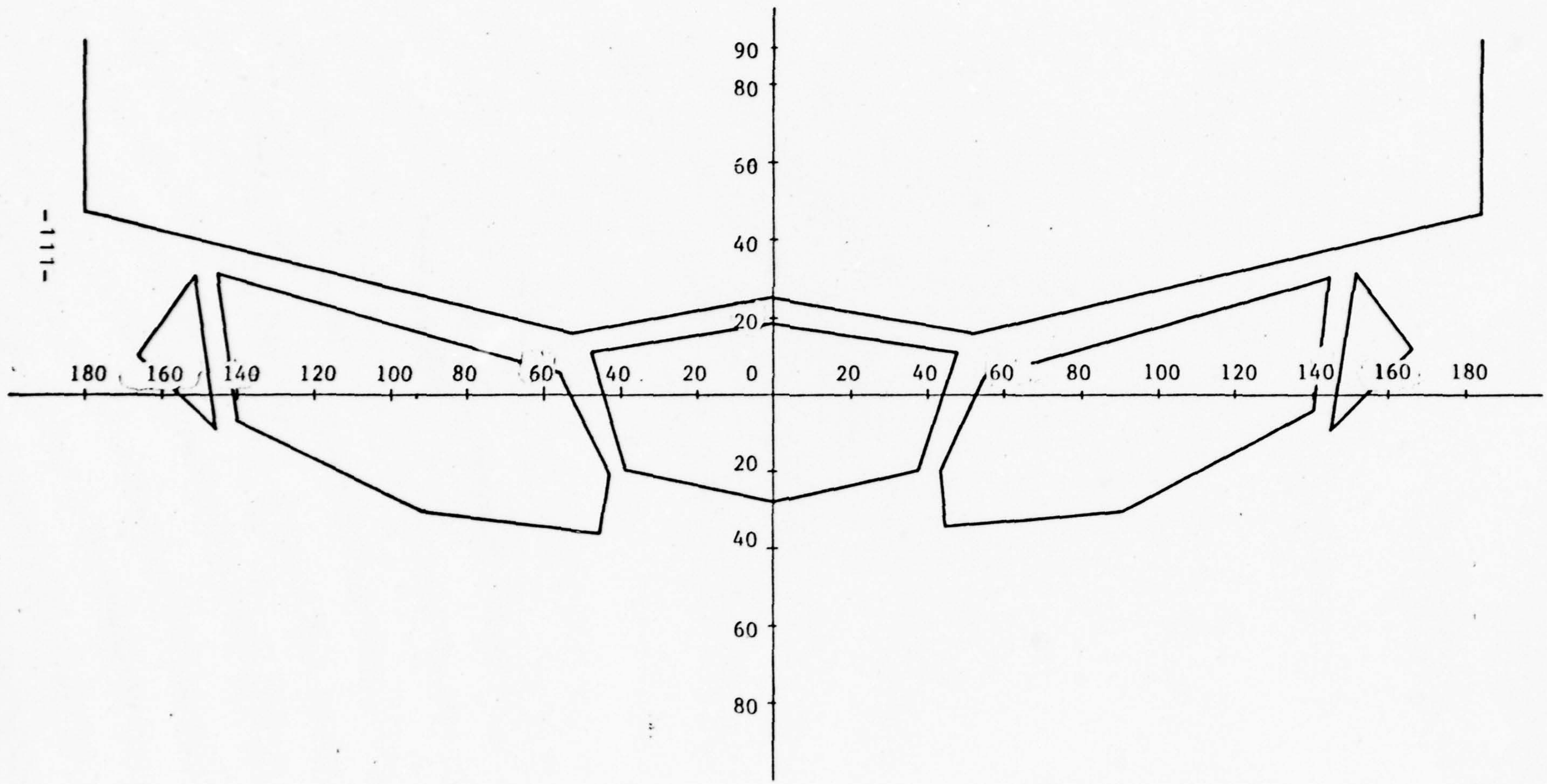


Figure 15
AAH CPG VISION PLOT

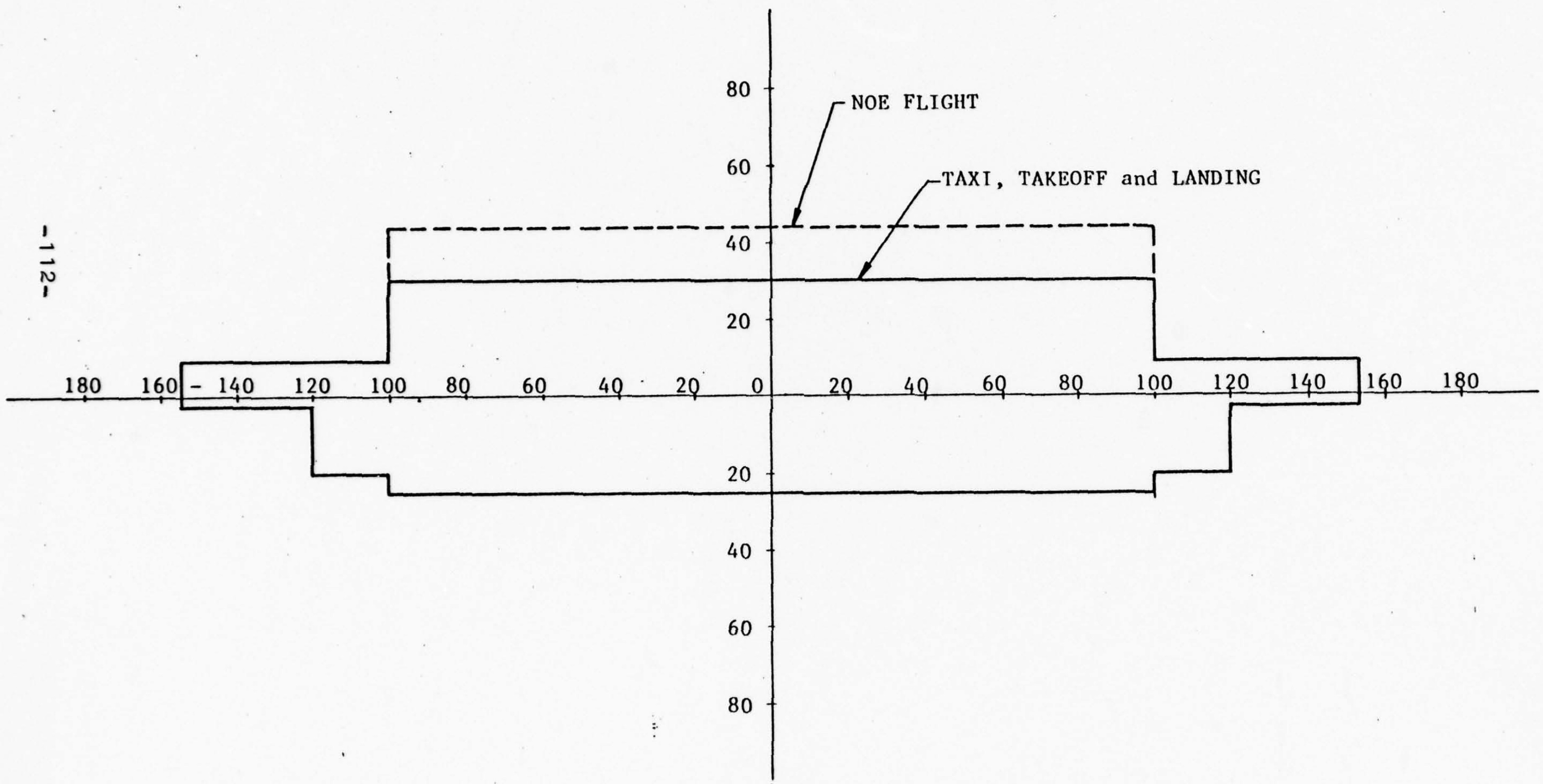


Figure 16
REQUIRED FIELD OF VIEW-ATTACK HELICOPTOR

Resolution

The next important characteristic for the pilot that is related to field of view is resolution. The desirable characteristic is to have real-world eye resolution capability, which is generally considered to be about 1 arc-minute. Coupled with the desired field of view, this would give a vertical resolution of 3,300 TV lines and a horizontal resolution of 10,800 TV lines at a 3 1/3-to-1 aspect ratio. Since these values are beyond the current state of the art, it is clear that some kind of compromise must be made between field of view and resolution. This compromise has been made on nearly all current systems in favor of retaining maximum field of view and accepting attainable resolutions from state-of-the-art image generation and display techniques.

Picture Quality

The next characteristics for these tasks relate to the more subjective aspects of picture quality.

Scene Brightness

The observed scene must be bright enough for the pilot to see clearly in a simulated daylight condition. From experience with other simulators, it is concluded that brightness of 5 foot-lamberts or better will accomplish this.

Color

The scene must be in color. For some aspects of terrain flight, color cues are highly important. For example, during NOE flight training, learning to stay concealed in forested, rolling country involves following creek beds to keep in the lowest part of the terrain. However, the creeks themselves are often invisible. The method of finding the path is to observe the trail of lighter green formed by the deciduous trees growing along the streams in comparison to the surrounding darker green pine or softwood stands. In

the navigation of the aircraft under these and similar conditions, color cues appear more important than textures.

Realism

In the design of training systems and programs, the goal of realism is ardently sought. Realism is complete in full scale operation of the aircraft, except that there are emergency operations that can not be done for reasons of safety. Combat simulation is "realistic" except that line of fire is restricted. Weather conditions are those existing at the time. Thus, even in the circumstances of greatest realism, there must be limitations for practical reasons. A prime objective is design of a system in which the proper level of realism is achieved to permit the broadest range of training tasks.

The simulation to be used in the AAHT will also be of limited realism. The visual system will be critically important to many of the training tasks. The designer must therefore be very careful to select the aspects of realism that are most vital to the training mission requirements, subject to constraints of technology and cost.

There is often a temptation to equate scene detail with realism. There is a relationship between a student's seeing windows on buildings and leaves on trees and his impression of a "real world" view. To the degree that leaves on the trees are important to training functions such as detection of concealed or camouflaged forces, they contribute functional (as well as cosmetic) realism. Extensive experience with relatively undetailed views in marine and aircraft simulators has demonstrated that functional realism can usually be achieved with limited detail as long as dynamic perspectives are maintained, surface shading is visually acceptable and moving objects in the scene behave as the viewer would expect the real article to behave. This is of great importance to

configuration selection when a choice must be made between strongly conflicting requirements. Of course, there must be a sufficient number and details of natural and cultural features and objects to allow accomplishment of specific tasks, such as maneuvering toward and around objects or terrain features.

The visual system will not provide scene brightness comparable to the real world on a bright day. Training is not cancelled on days when overcast skies lower scene brightness. Practical and achievable, though not fully "realistic," levels of scene illuminance can provide effective training in a functionally realistic way.

Night Operations

The pilot must also accomplish all the takeoff, flight and landing tasks at night. Depending on twilight, moon-phase, overcast or starlight conditions, some help may be obtained from the view out the windscreen. However, the primary night sensor is the Forward-Looking IR (FLIR) of the Pilot's Night Vision Sight (PNVS). For the PNVS, the relatively large field of view can be slewed by head motion, hand, or other controls through ± 90° azimuth and down to -45° elevation. Figure 17 shows the total field that can be covered by the PNVS instantaneous field. Thus, at night the pilot can see further towards his nadir than he can during the day, especially directly ahead, where the CPG blocks his view below about 25°. The scene observed on the Integrated Helmet and Display Sighting System (IHADSS) has the characteristics peculiar to the FLIR sensor of single color phosphor with video scene gray scales proportional to temperature differences, rather than reflected visible light. The pilot has essentially a monochrome area of interest (AOI) display at night of 30° X 40° which can be swept by his head motion through a wide azimuth and down to within

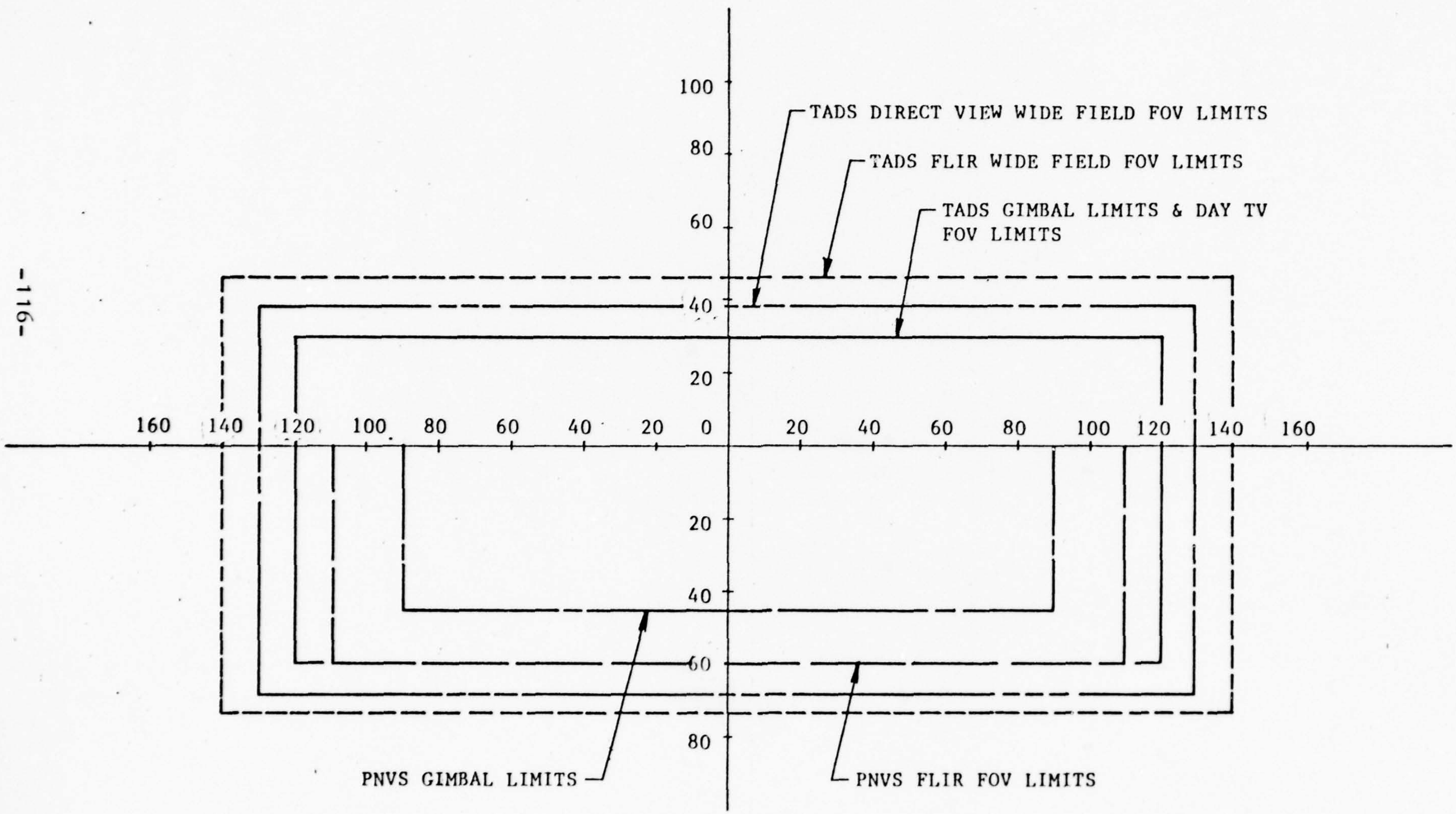


Figure 17
AAH TADS/PNVS SENSOR LOS LIMITATIONS

30° of the nadir. The CPG has an independent FLIR which has the identical instantaneous FOV and can be swept through an even greater azimuth (± 120°) but not as much below the aircraft. Thus, there are two independent AOI views that can look in different directions. This will certainly aid night navigation, although it complicates the trainer.

Viewing Aids

The pilot and CPG are both active in the task of target detection, recognition, and engagement. The pilot also has some tasks in threat engagement, but since the copilot/gunner has primary engagement responsibility, let us review his visual tasks and comment on the pilot as appropriate.

The CPG has, in addition to his view out the windscreen, the visual outputs of the three sensors of the Target Acquisition and Designation System (TADS). These include a direct view sight, a daylight TV with an extended red response sensor, and FLIR similar to that of the pilot.

The display for the CPG is a monocular eyepiece for the direct view sight, through which he can also select a display of the day TV, the FLIR or the pilot's PNVS FLIR. He also has, just below the eyepiece, a CRT display of about 4 inch size, on which he can select the outputs of any visual sensor except his direct view sight. Figure 18 shows the CPG visual display physical configuration.

The TADS sensors have considerable flexibility to aid the CPG in his detection, identification, and engagement visual tasks. Table 2 shows the field of view for each type of sensor plus the TADS turret gimbal angles through which their lines of sight can be directed. Similar data for the PNVS is included. Figure 17 shows these gimbal angles and fields-of-view excursions on the same scales as the pilot and CPG windscreen views. Comparisons show that the turret-mounted sensors give the AAH crew a larger total field,

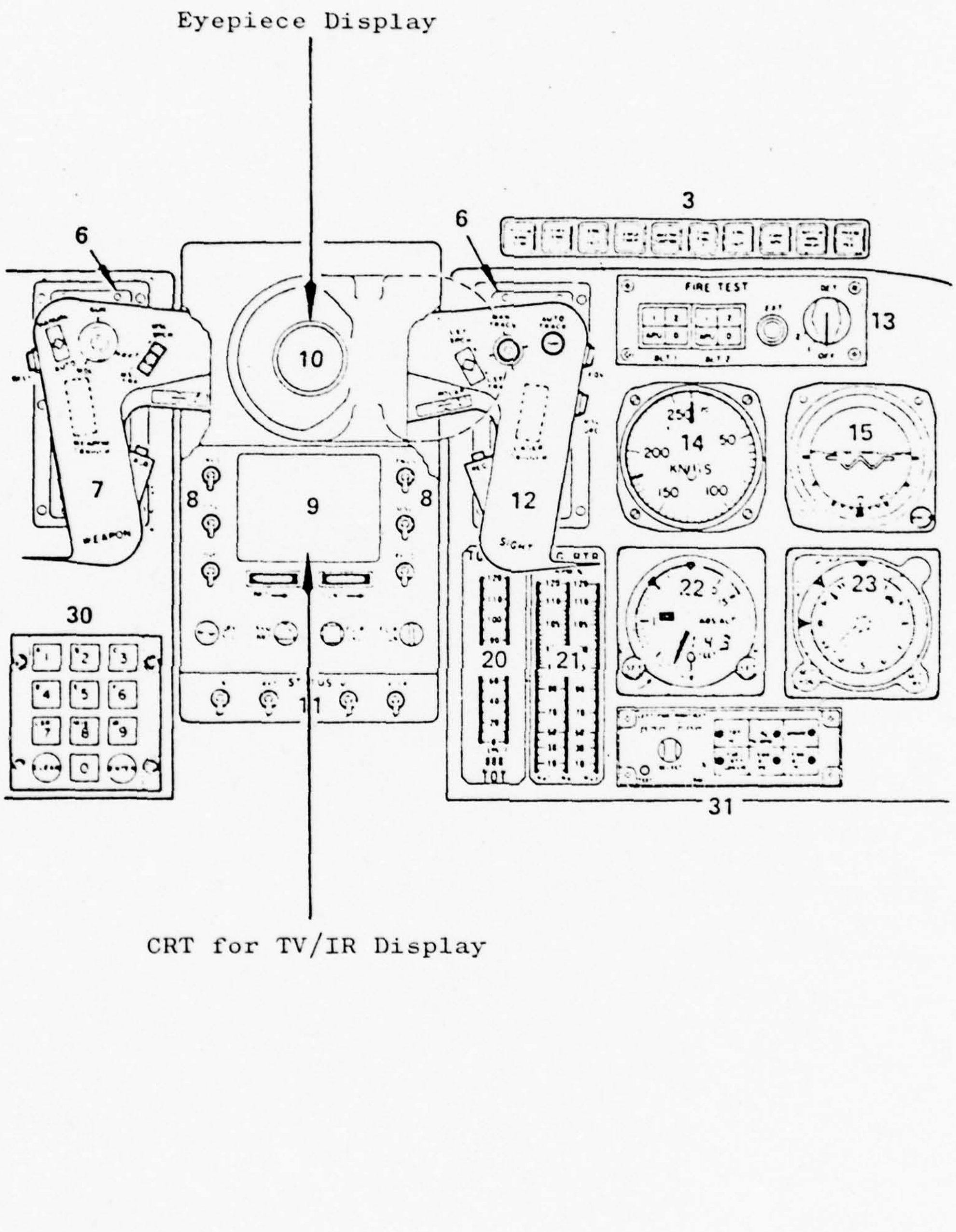


FIGURE 18. COPILOT/GUNNER VISUAL DISPLAYS

TABLE 2

TADS/PNVS SENSOR CHARACTERISTICS

SUBSYSTEM	GIMBAL ANGLE RANGE (AZ)	GIMBAL ANGLE RANGE (EL)	FIELDS OF VIEW VERTICAL/HORIZONTAL (All 3 x 4 Aspect Ratio)		MAGNIFICATION Panel CRT (20°)	MAGNIFICATION Eyepiece (64°)	MAGNIFICATION IHADSS HMD ($30^{\circ}x40^{\circ}$)
TADS	$\pm 120^{\circ}$	$+30^{\circ}$ -60°					
FLIR (Night) (Pilot and CPG)			Wide	$30^{\circ}x40^{\circ}$	0.5	1.6	Unity
			Int.	10° to 18°	1.4	4.6	2.9
			Narrow	2° to 4°	6.7	21.0	13.0
Day-TV (Pilot and CPG)			Wide	2° to 4°	6.7	21.0	13.0
			Narrow	0.5° to 1°	27.0	85.0	53.0
Direct View (Day) (CPG Only)			Wide	18° to 23°	-	3.2	-
			Narrow	3.5° to 4.5°	-	21.0	-
PNVS	$\pm 90^{\circ}$	$+0^{\circ}$ -45°					
FLIR (Night) (Pilot and CPG)				$30^{\circ}x40^{\circ}$			Unity

especially downward, than they have from the windscreen.

Thus, the simulator must enable similar instantaneous field of view (FOV) choices, the same total field, and the same visual characteristics as the TADS sensors, i.e., a very high-resolution color visual scene of either 20° or 4° FOV for the direct view sight, a monochrome scene of medium resolution with a 3° or a 3/4° field of view for the day TV, and a high resolution IR scene of 40°, 14° or 3° FOV for the FLIR.

The content of the observed scenes is critical to threat detection, recognition, and engagement training. The key task of the AAH is to engage tank and tank-like targets with missiles, and personnel or light-materiel targets with stowed weapons. Thus, the inclusion of such objects, with independent maneuver and motion capability, is a vital requirement on the visual subsystem. In addition, the ability of such moving targets to hide behind other objects in a realistic way, such as a tank hiding behind a terrain rise, will significantly enhance training effectiveness. The other aspects of an engagement scene, including missile plumes and trails, tracers, and weapon effects from own and friendly craft and from the threat array, are other important items of desirable visual scene content. For all moving objects, a minimum quantity of five is probably necessary, with up to 25 very desirable, for more realism to the total battle array. While target information usually comes from a friendly element, autonomous detection, identification, acquisition and engagement of threat targets are also required operating modes. Here, the emphasis must be on target and background model realism, and on the visual resolution necessary to accomplish detection and recognition at the proper ranges. While the specifics are classified, suffice it to say that the resolution requirements on the simulated visionic equipment in the trainer are quite severe.

Crew Coordination

With the capability for either crew member to see the windscreen visual scenes or any of the TADS/PNVS sensor scenes (except the direct view, available to the CPG only), the availability of visuals, with the above characteristics, together with functional simulation of the related controls, will enable the crew coordination vital to a realistic crew training mission. Such a mission typically involves receiving a target handoff, acquiring the target, selecting the proper weapon for target engagement and using the flight mode and technique of target attack best suited to the situation.

Little data on specific use of the visionics with the weapons systems was available, but from the specification data it would appear that a reasonable assignment and use would be as follows.

Daylight Operations. The gunner uses his windshield view, the direct view sight, and the daylight TV system for engagement using the Hellfire missile. A typical sequence might be as follows: The attack helicopter is ordered to an area where a scout aircraft has detected an armored threat. Enroute to the target area, the attack helicopter communicates with the scout and gets data on the target's grid location. At about 3500 meters, the attack helicopter uncovers. The gunner uses the direct sight in wide field to search the area of the target grid location. On detecting a possible target, he switches to the narrow field to recognize it as a tank and identify it as hostile. He then switches to the TV in wide field in which the target is slightly more magnified and uses the TV tracker to gate and lock on the tank. The panel CRT display allows the gunner to see "heads up". He then switches to the TV narrow field for better input

to the fire control system if conditions allow tracking to continue. Finally, the gunner triggers the laser designator (assuming that the scout is not laser-equipped) and releases the previously coded and selected Hellfire missile, which homes on the laser-designated spot to destroy the tank.

The pilot uses his IHADSS helmet mounted sight (HMS) normally to direct the 2.75-mm rockets for area fire, and the gunner uses his HMS to direct the flexible weapon. The weapons can be interchanged as desired although the CPG does not usually fire the rockets.

There is an extensive ability to exchange roles, with the gunner having flight controls and the pilot having the ability to use his IHADSS helmet mounted display (HMD) to see any sensors' video output. These are all used as backup modes or for emergencies (see Table 3).

Night Operations. The pilot uses his PNVS and sets a 30° x 40° field at 1:1 magnification on his HMD. The CPG uses his FLIR in wide field on his HMD to navigate while the pilot flies the aircraft. For target engagement, the CPG uses the FLIR sensor data displayed on the panel CRT to detect the target, recognize and identify it with progressively narrower fields of view, track it for fire control computations, designate it for missile launch or engage it with flexible or fixed weapons.

TABLE 3

PILOT AND CPG VISIONICS BREAKDOWN

	PILOT		GUNNER	
DAYLIGHT OPERATIONS	Normal	Backup	Normal	Backup
Sensor	Naked Eye	TADS TV	Naked Eye TADS Direct View TV	None
Display	None	HMD	Eyepiece Panel CRT	HMD
Sight Reticles	HMS	None	HMS	None
NIGHT OPERATIONS				
Sensor	PNVS-IR	TADS-IR	TADS-IR	PNVS-IR
Display	HMD	None	HMD	Panel CRT

Image Generation and Display Components and Technology

Overview of Technology. A number of techniques are available for consideration in providing the visual displays required for the AAH-Flight and Weapons Training System. Figure 19 shows a matrix summary of the primary alternatives for the out-of-the-windscreen scenes. In each case, the origin of the visual scene is shown at the bottom of the chart. Proceeding upwards in each case, the sensing, transmission and synthesis of the scene is shown. This group comprise the techniques of image generation. The upper columns comprise the image display methods, showing how the picture is projected, and finally how it is displayed for the observer.

As the matrix shows, there are these four basic approaches to picture production: filming a sequence of real-world events from a helicopter; projecting the silhouette of a three-dimensional model onto the screen by means of a point light source; generating the visual scene in a digital computer; and moving a television camera within a three-dimensional model. The first three approaches are quite compact, but space for the model board will be required if the television/visual model approach is selected.

Of the four, the cine-film technique is the simplest and least expensive. Panoramic camera and projection systems exist, and techniques have been developed for matching and blending the edges of adjacent pictures in multi-channel systems. The critical limitation, of course, is that such a display cannot respond to helicopter maneuvers; once filmed, the sequence of events is immutable. The usefulness of the technique is therefore limited to representing specific open-loop problems.

The Netherlands Ship Model Basin has developed a silhouette projection technique for its ship maneuvering simulator

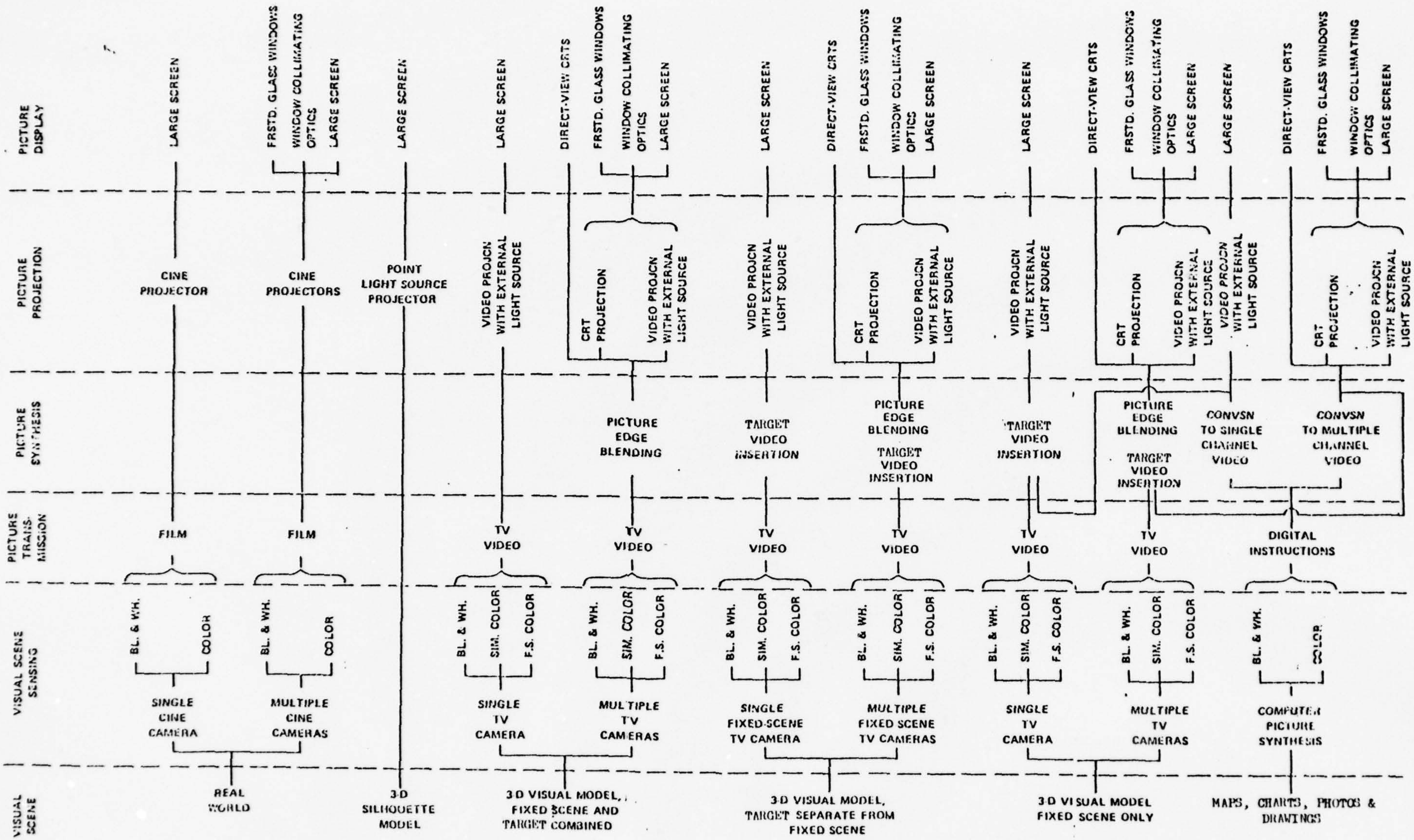


Figure 19. Visual Display Alternatives

in which the visual image responds properly to own ship maneuvers. A three-dimensional model of the visual scene surrounds a point light source at the center of a large, cylindrical screen. The light source throws shadows of objects in the visual scene onto the screen. Colored shadows are obtained by making the models of colored glass. Change in own ship position is represented by translating the model relative to the light source, changes in heading by rotating it about the light source. While this technique does provide maneuvering freedom, scale considerations necessarily limit it to relatively small areas; extension to larger areas would require frequent model changes. Moreover, the inclusion of a number of independently-maneuverable targets poses very serious engineering problems. This technique is too limited to be considered further.

Perhaps the most flexible way of producing a visual image is to generate it in a digital computer. A number of companies have developed techniques of computer image generation. The visual scene is made up of straight-line segments which constitute the edges of objects. The location of each edge in three dimensions is stored in the computer. Given the position of the observer, the computer synthesizes the appropriate view. The resulting computer instructions are converted to television video for display. Color pictures can be obtained by defining the color of each surface bounded by stored edges. One company has delivered a 4000-edge machine for ship simulation; displays with double or triple that number of edges are entirely feasible.

Picture quality is necessarily somewhat schematic, but scenes are readily recognizable and move with full dynamic fidelity. A major advantage is that representation of multiple movable targets presents no special problems.

The most life-like display is generated by using a three-dimensional visual model. One or more television cameras,

translated horizontally and rotated in heading by a servo-driven transport mechanism, represent the helicopter crews eyes. The model in such a system tends to be very large. Choice of model scale is governed by the requirement that significant objects do not become unmanageably small. If, for example, the model of an 8-foot-wide tank is to be at least 0.1 inch in size, model scale cannot be smaller than 1000 to 1. As a limit, a model scale of 2400 to 1 may be attainable by allowing small objects to be larger than life size. Even at this scale, however, a 20-mile route of flight requires 50 feet of model.

Representation of targets is another serious problem. To have several targets moving independently on the model terrain presents obvious difficulties. The alternative is to generate synthetic target video, and to insert it electronically into the fixed-scene video. This might be done by mounting off-scene target models on servo-driven heading turntables, and scanning them with one or more separate cameras. Scan conversion techniques can then be used to change image size with range, and to position the image properly within the frame as a function of target relative bearing. Standard television techniques are available for inserting the targets into the fixed-scene video. While the technique is technically feasible, it becomes complicated and expensive as the number increases. A possible alternative may be to mix computer-generated target video with the fixed-scene video from the scale model.

Once the composite video signals have been generated, they can either be viewed on cathode ray tubes through optics or projected onto display screens. For sighting aids on the helicopter, the cathode ray tube itself can serve as the projection light source, but a brighter source is required for large-screen projection. A number of video

projectors exist - for example, Gretag-Limited's Eidophor and General Electric's Light Valve - which use the video signal to modulate the light from a high-intensity light source. The scan circuits and the optics can be modified to conform to the simulator's field-of-view requirements.

Color television systems can make use either of simultaneous color or of field-sequential transmission. In simultaneous-color systems three separate video signals, corresponding to three primary colors, are generated and transmitted side by side. Bandwidth requirements for a given angular resolution are only slightly greater than for black-and-white video. The field-sequential approach eliminates the need for three separate video channels by transmitting the three colors in sequence on a single channel. In order to maintain the same overall frame rate, individual color fields have to be transmitted at three times the basic rate, and the system therefore requires three times the bandwidth of black-and-white video to retain the same resolution.

In addition to resolution, depth of focus and signal-to-noise ratio are important to picture quality. In the simulator visual display, the trees a few feet below the helicopter should be as sharply in focus as the target on the horizon. For the television camera, this implies a depth of focus from fractions of an inch to infinity. Large depth of focus can only be obtained with a very small aperture which, in turn, reduces the light entering the camera and consequently reduces the signal-to-noise ratio. Insufficient signal relative to inherent noise results in "snow" on the picture.

The design of a television system for the simulator must arrive at a suitable compromise between resolution, depth of focus, and signal-to-noise ratio.

Generation and Display Components

A variety of components are available for consideration in providing the visual displays required for the AAH flight and weapons training system. Some are mature and well tried, others are newer and still developing, and others are as yet untried and only in feasibility demonstration stage. Each has unique features which may be advantageous or disadvantageous for the AAH training problems. To bring some order to the evaluation of the technology and components, this section will list the methods available for image generation and discuss those characteristics pertinent to this training system. The same will then be done for the image display techniques. From this review, possibilities for the basic generation and display of the visuals, specific systems recommended for the visual system module will be justified using the training requirements as the driving force.

These configurations will then be reviewed and evaluated for their ability to meet the technical, availability, logistics and cost effectiveness criteria for the different visual modules required for the AAH training system.

Image Generators

Image generators fall into three broad categories based on the storage media of the visual data. The categories are:

1. Film-based generators
2. Model board generators
3. Computer image generators

Let us review what these image generators are, how they differ, and what characteristics make them unique. Table 4 lists the primary generator types and compares a series of specific characteristics with those that are desired for AAH

TABLE 4

AAH-FWS - IMAGE GENERATOR - MATRIX OF POSSIBILITIES

CHARACTERISTICS OF INTEREST

IMAGE GENERATOR TYPE	VIEWPOINT MOTION FREEDOM	SCENE DENSITY	MODEL REALISM	FIELD OF VIEW MAXIMUMS	RESOLUTION (OUT THE WINDOW)	NO. OF MOVING OBJECTS	MOTION FREEDOM MOVING OBJECTS	EXISTING SYSTEM EXAMPLE	TECHNOLOGY STATE/ FUTURE GROWTH	COST EFFEC-TIVENESS ESTIMATE	SPECIAL RESTRICTIONS OR CHARACTERISTICS
Desired characteristic for AAH training	Unrestricted	High-Real World	High-Real World	$\pm 90^\circ$ azimuth $+ 15^\circ$-40° EL	One arc-min.	25 or more	Unrestricted		Low risk-high growth potential	Benefit/cost ratio high	No special restrictions
Film generators camera/film	Severely restricted to minor variations from fixed path	High-real world	High-real world	360° AZ 50° EL	One arc-min.	None can be done by superposition	N/A	Fokker ship trainer	Low risk-little growth potential	Low	Film record or scene is immutable
Model board/TV camera/probe optics	Unrestricted within gaming area-limited in minimum height above surface	Can be high-near real world (Depends on modelling scale)	Can be high-near real world scale-dependent	$\pm 70^\circ$ AZ $+$ 15-20 EL (3 channels)	8 arc-min. (TYP)	Small - 1 to 5	Fixed paths only for required fields of view	2B33	High maturity -low risk-limited growth potential	Medium	Physically very large-may require special building - high power consumation limited to 3 channels by probe optics
Laser-scanned model board	Same as TV model board	Same as TV model board	Same as TV model board	$\pm 175^\circ$ $+ 20^\circ$-40°	7 arc-min.	Same as TV model board	Same as TV model board	None existing	Very low maturity, high risk-but high potential in FOV vs resolution	Medium	Same as TV model board plus many unknowns
Computer Image Generator	Unrestricted within gaming area	Medium	Medium	Not restricted	Restricted only by computation-3 arc-min. systems in being	Can be high-5-25 or more	Unrestricted	ASUPT, CAORF	Medium maturity-low-risk very high growth potential	Medium to high	Requires special hard-wired processors. Requires special data base generation
Hybrid model board/TV with keying (video insertion) of moving objects (can be generated by CGI or TV camera/object model)	Same as TV model board	Same as TV model board	Same as TV model board	Same as TV model board	Same as TV model board	Can be high-1-10 or more	Unrestricted	LAMARS	Fairly high maturity. Low risk-limited growth potential	Medium	Physically identical to TV/model board. Moving objects always appear in front of background - they cannot be hidden by other parts of the scene

training. It also summarizes the cost relationships and technology status, with a conclusion about its applicability to an AAH training system.

Film Generators. Generating film visuals is simply a matter of taking pictures of the real world with one or more cine cameras. The film storage medium then forces the display to the cine projectors. The state-of-the-art in film and film cameras is highly developed and mature. Very high resolution cine pictures can be taken of wide or narrow angle views and mated to show even 360° azimuth scenes. Object density in the scene faithfully reproduces the real world, and resolution on large-format film (such as 70 mm) with proper design of multiple camera installations for the total field desired, can meet almost any requirement for detection and recognition at ranges comparable to those in the actual situation.

Generating film for a flight simulator involves flying over the desired terrain with an airborne camera installation. Thus, if specific terrain locations are desired, it must be in the power of the visual generating agency to accomplish the fly-over. Also, if any other moving objects, friendly or threat, are to be simulated, they must be available and under control also. This is not a restriction in domestic or allied territory, but is a significant one for potentially hostile areas.

Perhaps the most significant limitation of film generation (and display) for simulation purposes is the fixed nature of the results. Once taken, film allows only the reproduction of those specific positions and conditions with little or no variation.

Thus, its application is limited to essentially open-loop simulation. The significant advantage is widely-

FIGURE 18. COPILOT/GUNNER VISUAL DISPLAYS

available, flexible, mature components at relatively low cost to accomplish the image generation task.

Model Board Generators. Model board visuals are television pictures of a scaled physical model of an area of terrain containing features or objects of interest. The pictures are produced by an optical probe and one or more television cameras mounted on a servoed gantry system so that the viewpoint can be controlled in position and altitude in relation to the board. The optical system has very stringent requirements including good resolution, wide field, large depth of focus, large aperture, and small physical size to allow close approach to the model board. These conflicting requirements result in long, narrow optical probes that can show perhaps a maximum field of 140° in azimuth and have very small apertures for reasonable depth of focus. Such systems require high light levels on the model board to get enough light through to the TV camera faceplates, making power consumption an operating cost problem.

However, TV camera/probe scanned model boards make up the bulk of existing image generators for flight simulators. Model boards have been a preferred environmental scene storage method for a number of advantageous characteristics. Chief among these is the ability to accurately reproduce terrain contours, and natural and cultural visual features. A high order of fidelity in scale and in object details has been achieved as model making was improved and photo transfer techniques have been applied. Model board generators can produce very high scene object densities and, with proper gantry/TV camera/optical probe sensors, provide highly realistic visual scenes of the environment from a moving aircraft. The choice of scale for the model board is very important because the total area modeled vs. the amount of detail physically achievable in

each object must be traded off. Where the range is too wide for reasonable compromise, either multiple boards of different scales must be used or specific areas of one board can be modeled to different scales and scale switching arranged. Another approach is use of very large boards which then become a space and power problem, requiring special buildings and consuming significant energy.

Another serious limitation of model board generators is the difficulty associated with having moving objects in the field of view. Because the scene to be observed is produced from a real scene in miniature, moving objects in the observed scene must also be in the real scene in miniature. This drastically limits their motion capabilities because of the physical restrictions involved. Moving miniatures propelled via slotted pathways or moving magnets have been used but these are restricted to relatively simple preprogrammed pathways which may limit their use for training. While radio-controlled models are possible with full motion freedom, the scale of models required is incompatible with present independent control systems which are relatively large, complicated and unreliable. It is also possible to key in (insert) video from a separate source to show a moving object that has an unprogrammed path. This method is limited, too, since it cannot show the moving object hidden behind other objects of the static scene. In addition, as scale and perspective of the static scene change to a moving observer, the system must do the same to the moving object to maintain compatibility in the combined scene. A refined version of such a moving object system may be the best that can currently be planned for a model board image generator, despite its shortcomings.

In summary, model board generators have been developed over the past several decades and the technology is quite mature. The refinements are essentially all in place and major improvements over existing systems await

visionic equipment in the trainer are quite severe.

technological breakthrough, rather than further development.

One such technological breakthrough is being attempted by NTEC with Air Force support in the wide angle laser scan system. This is a model board generator where the picture output is developed by a laser based system in which a raster scanned laser beam's reflection from a model board is picked up by photomultipliers whose outputs are combined and processed to form video signals. Feasibility studies have been completed and a breadboard model is under contract. The key advances being sought in this program do not relate to the model board limitations addressed thus far, but to obtaining a wide field with adequate resolution in a single channel.

Sperry has been favorably impressed with the depth and extent of the feasibility and breadboard work to date on the wide-angle laser scan system and its potential for the AAHT application. The development of a practical and usable visual system requires significant advances in several areas of laser technology, and thus there is significant risk in considering it as the primary image system for a scheduled program. One area, that of 100 MHz laser modulator technology, Sperry believes is not now near a solution. Two specific technical problems are outlined below. Both are based on data from the American Airlines final report on the WALVS feasibility study. The first shows that the modulator crystal will experience a serious temperature rise and the second that the modulator will require very high drive power due to dielectric power losses.

Heating Effect in Birefringent Crystal

Assume all heat transfer from crystal is by radiation.

$\frac{\text{Power}}{\text{Area}} = E_t \sigma (T^4 - T_o^4)$ ITT Handbook 4 ed. p. 369

E_t for glass = 0.94 at 293°K AIP Handbook 1957 p. 6 - 71

$\sigma = 5.67 \times 10^{-12}$ watts/cm^2 $°K^{-4}$

For best case, T_o is room temperature = 293°K

Area for crystal $\frac{1}{2} \times \frac{1}{2} \times 2\frac{1}{2}$ inches

$$A = \left[2(\tfrac{1}{2} \times \tfrac{1}{2}) + 4(\tfrac{1}{2} \times 2\tfrac{1}{2})\right] 6.25 = 34.38 \text{ sqcm}$$

$$T^4 - T_o^4 = \frac{P}{A E_t \sigma} \quad \text{and} \quad T^4 = \frac{P}{A E_t \sigma} + T_o^4$$

Assume power dissipated in the crystal is 2 watts

$$T^4 = \frac{2}{(34.38)\ (.94)\ (5.67 \times 10^{-12})} + (293)^4$$

$$= 1.828 \times 10^{10}$$

T = 367.72°K or a temp rise of 75°C

Power Consumption in E-O Modulator

Dimensions of capacitor plates: 5 X 0.5 inches-

spacing 0.5 inch

Based on p. 110 of AA report

$C = 0.225\ E_r \ \frac{(N - 1)\ A''}{t''}$ uuf pg. 133 of ITT Handbook '57 ed.

E_r = 90 for KDP pg. 5 - 155 AIP Handbook '57 ed.

$C = 0.225\ (90)\ \frac{2.5}{0.5} = 101.25$ uuf

Power lost in dielectric

$W_e = wCV^2 \tan \delta$

$\tan \delta$ for KD*P is 5×10^{-4} per Eo Vaher

$$W = 2\ (10^8)\ (10^{-10})\ (3)^2\ 10^4\ (5 \times 10^{-4})$$

$$= 2.83 \text{ watts}$$

$$\text{Drive power} = fCV^2 = (10^8)\ (10^{-10})\ 10^5 = 10^3 \text{ watts}$$

These kinds of problems may cause delays or lower than expected performance from the wide angle laser scan system. Thus, completion and evaluation of the breadboard model is necessary before any decision to apply this visual technology to the AAH trainer can be taken.

Computer Image Generators. Computer image generators are a relatively recent development in simulation. Starting only in the last half of the 1960's, computer generated imaging (CGI) technology has experienced steady growth in capability, capacity, flexibility and applications, expecially in simulation. Not only is no end to this growth in sight, but acceleration of development is more probable than deceleration. Computer image generators are oriented heavily toward memories, and the rapid growth of memory technology, witness CCD and bubble memories, will sustain continued advances in CGI.

Computer image generators store visual data in the form of locations of object points or vertices in three dimensional space in a computer mass memory, such as a disk. The total stored material is called the data base. The CIG system extracts that part of the data base that can be seen from the observer's position and holds it in an active storage memory. Every television frame time, the three-dimensional object data is taken from the active memory, transformed, and placed in proper perspective projection in two dimensions as it would be seen by an observer. The two dimensional perspective data is scan converted to TV raster format, parts of objects hidden by other objects are detected and removed and the resultant digital data is converted to analog video signals at television rates. Since standard

TV rates in the United States require 30 picture frames per second, the image generator, parts of which are high-speed, hard-wired digital processors, recomputes a new picture every 1/30 second.

As with model board generators, the architecture of the computer image generator leads directly to both its strengths and limitations.

The data base is modeled by converting maps, charts, drawings or photos of natural and cultural objects into digital form. The conversion process, although partly automated, is under the control of a human modeler. The modeler must know the parameters of his generator and the visual results desired, because his primary task is to make the most effective use of a finite equipment capacity to produce the desired scenes. Because the computer image generator can store a specific number of points or vertices, and can process only a part of these in a 1/30 of a second through to display, the resulting visual scene has a limited amount of detail at any moment.

The modeler also has constraints on how to model objects. If he models them with too few vertices they will look quite unrealistic, like a poorly drawn cartoon. If he uses many vertices or "edges" (which are the straight lines between vertices) he may rapidly use up most of the storage or processing capacity of the generator before it can display all the objects he wants to be able to see.

Thus, for a wide field of view, in conditions where there are many details we want to see in the scene, computer image generators are limited to showing only a certain amount of detail and no more. This capacity may be utilized to show a large number of low detail objects or a smaller number of highly detailed objects.

One significant characteristic of CGI is the ease of placing moving objects in the visual scene and the flexible way in which they can be inserted, moved and removed. Since the generator reaches into active memory for object locations and processes a new set every 1/30 second, all we need do for a moving object is to calculate its position in space at that rate and place it in the active memory. In fact, this is done for a single point of the object, its centroid; and the generator takes the object itself, such as a tank, from a part of the memory and places it at the new centroid location every 1/30 second. Thus, there will be a tank in the scene which can move on any path chosen by an instructor or a stored scenario program. A number of threat vehicles can operate independently and simultaneously, but they contribute to the limited total scene edge capacity of the generator.

Conclusions and Recommendations on Image Generators

It is clear from the review of image generators technology that no single generation technique provides all the desired visual characteristics for accomplishing the required AAH training in a single trainer configuration. Sperry SECOR has chosen to recommend a training system composed of an integrated pilot/gunner trainer, a separate gunner trainer, and the YAH-64 aircraft itself, partly because of this fact.

The breakdown of major crew member tasks and their effect on image requirements have been detailed elsewhere in this report. The resulting choice is to optimize the visual simulation separately for the gunner and the pilot, while still providing the best available capability for crew integration. The gunner, who does not directly control the aircraft flight, has tasks requiring very high resolution. For his trainer, then, cinematic techniques offer the detailed realism and high resolution required for the out-the-windscreen view. The open loop nature of the film visual system is not a serious handicap in training the man who does not fly the aircraft.

The choice for the pilot/gunner image generator is less clear. While the emphasis in the pilot/gunner trainer is on the pilot, it is vital that crew training be considered, so integrated tasks must be able to be trained. Many of these involve use of the TADS/PNVS sighting aids. Visual requirements for these sighting aids were discussed earlier in this section. When these are combined with the out-the-windscreen view requirements for both crewmen, a formidable visual simulation task emerges.

Table 5 is an attempt to summarize the requirements for a system to do pilot/crew training. It lists the parameters considered, and shows for each how the model board and computer image generation approaches would compare. Because of the closed loop nature of the pilot and integration training tasks, film is not considered.

When the comparison is put on this basis, the advantages of CGI show up rather clearly. These advantages include the flexibility of controllable moving targets, independent narrow field-of-view scenes for the sighting aids, simple IR scene simulation integrated with the day/night scene data base, and ease of simulating weapon effects. CGI exchanges more lifelike realism in scene object quantity and details for a controlled detail level representational model scene. For these reasons, CGI is the image generation system selected by Sperry SECOR as the first choice for the pilot/gunner trainer.

If the wide-angle laser scan system can make the technological breakthroughs needed, and demonstrates that it is sufficiently practical for use in the AAH trainer, then the visual system for the pilot/gunner must be reevaluated. The laser scan system can substitute completely for the windscreen display for the pilot/gunner trainer. However, it cannot readily provide the video inputs for the TADS/PNVS displays. Thus, a laser scan based visual module would likely need to be a hybrid system because of the wide range of integrated training requirements.

TABLE 5

AAH PILOT/GUNNER TRAINER

VISUAL SIMULATION SYSTEM

PARAMETER	MODEL BOARD APPROACH	CGI APPROACH
1. Scenery content; terrain contour, terrain texture, vegetation, trees, curves, hills, gullies, ripples.	Lifelike scene detail, resolution limited by TV system.	Representational models, limited by CGI Processor capacity, data base modelling level and real-time software. Newest techniques can assure all capacity is used to place only visible, significant scene elements on display.
2. Moving targets; random direction, varying range, varying speed, various target types (soft,hard)	1. Pivotal Track - Limited Range 2. Radio Controlled Magnet Coupling - Horizontal model bd. 3. Inset with camera and scan conv. - accuracy problem 4. Separate gantry - accuracy problem	Moving targets easily implemented with multiple moving coordinate systems. Target position and heading computed in central data processor and visual system places selected model at those locations in real time. Instructor or software can control target direction, speed, range and type.
3. Optical viewing, magnified for TADS/PNVS	1. Reimage full scene in probe with high resolution camera onto: a) Scan Converter b) Secondary screen and camera servo	Two separate CGI pipeline processors driven from the same host computer with one data base.

4. FLIR sensing TADS/PNVS	1. Simultaneous IR model board and gantry.	Data base coded for both daylight color and IR gray scale proportional to temperature in the proper IR band. Choice of day or IR operation activates data base code.
5. Weapons effects; flash, smoke, tracers, missile plume.	1. Inset flash, smoke and dust with mech. gen., camera and scan conv. to provide size and position control under computer control.	Weapons effects at remote locations modelled in data base and called up in proper position and time by central data processor. AAH firing flash, smoke can be modelled as colored haze, partly obscuring all objects from view. Tracers modelled on moving coordinate system driven from CDP.
6. Day/Night; landing lights, cultural lights	1. Landing lights - lights on probe illuminating the path - system lights out 2. Cultural lights - use of fibre optics.	On board and cultural lights modelled in data base at proper intensity, modified by range to own AAH to limit of display dynamic range of brightness. Path illumination provided by simulated directional illumination lobes from on board lights interacting with objects in flight path, returning realistic intensity variation.
7. Simulated eye heights	1. Simulated with the scan converters as part of item 3	Parallax of naked eye view minimized by screen distance. IHADSS directional pointing angles corrected by CDP for parallax. Magnified sight images corrected for eye height in CGI system.

8. Image quality; dynamic fidelity to judge velocity, rate of closure	1. Requires a high resolution, low lag camera tube such as the 4" Image Isocon. Lag is limited to 2% at 50 ms. Resolution is 1000 TV lines.	Resolution of 1000 TV lines feasible. All perspectives are correct, so cues of image size growth rate, object motion and occulting are proper. Missing cues are changing fine details in near field - not modelled.
9. Visual cues; image detail and dynamic system performance.	1. Visual and motion cues exist from the texturing done on the model board surface.	Selected level of modelling provides chosen detail and true and visual cues for those objects. See above for motion cues. Dynamics do not degrade visual quality until rates causing physical separation of TV raster fields.
10. Line of sight; for TADS/PNVS	1. Multiple probes - problem of different eye points 2. Multiple model boards and gantry	CGI processor produces 180° instantaneous scene, so pilot and gunner can see over wide field. Separate CGI channels needed for independent magnified views.
11. Performance trade-offs. Order of precedence: 1) Resolution 2) Dynamic realism 3) Scene brightness 4) Distortionless image	1. Resolution - Practical System limitations of 7-8 min/L.P. 2. Dynamic Realism - limited by camera tube - with an Image Isocon - 2% lag at 50 ms. 3. Scene brightness - depends on proj. and screen width	1. Resolution - CGI system can be built for any resolution. Multichannel displays may be needed to produce that resolution for the eye - cost/power/performance tradeoff. 2. No limitation to dynamic realism. CGI produces every element of every picture digitally. Assuming proper video bandwidth, dynamics must cause raster field separation to cause picture distortion.

	5 Ft.-L. practical. 4. Distortionless Image - requires Distortion and Scan correctors for the cameras	3. Screen brightness same as model board - function of display - 5 ft.-Lamberts practical 4. Pictures generated without distortion. Projection geometry may cause distortions, but optical, electronic or picture generation distortion corrections can be applied.
12. Refresh rate 30 FR/sec.	1. Standard of 30 FR/sec, 60 FLDS/sec for B/W 30 FR/sec, 180 FLDS/sec for field seq. color	Same standards as model board. Digital picture is produced asynchronously, so any type of TV SYNC standards can be used.
13. Contrast ratio; 15:1	15:1 contrast ratio practical	Function of display - 25:1 contrast ratio practical
14. Stability; 0.5% min. of height	No data	Picture generation stability $\pm \frac{1}{2}$ resolution element. Display stability of 1 resolution element practical. This is $\frac{1}{4}$%.
15. Luminance; 5 FT.L., uniform to 30%	1. Achievable with unity gain screen.	Luminance practical. Uniformity depends on display geometry - may need low gain screen.

Image Displays

Image displays are of two basic types. Real image displays present an actual picture on a surface, such as a screen or CRT face, which can be seen by observers. Virtual image displays place an optical system between the real image and the observer's eye so that the image appears to be located at infinity to the viewer. Any of the real image display methods can be used as the image input to a virtual image display.

Table 6 lists the image display components and makes comparisons to desired characteristics, as in the previous chart on image generators.

Real Image Displays

Film Projector/Screen. Film projectors, showing images on a screen, are familiar to all. Capable of high brightness, large-screen projection systems are well-developed, and techniques of matching and blending the edges of adjacent pictures in multi-channel systems are in common use. The limitation is still that the display cannot freely respond to own aircraft maneuvers. For open-loop training situations, however, the high-resolution, wide fields of view, economy, and mature technology of film display make it an attractive choice.

Video Projectors. All the non-film image generators produce TV video as their outputs. This video can be displayed directly on a TV monitor CRT, and for the simulation of the cockpit displays from the TADS/PNVS, this is suitable. For the outside view, however, a large field of view is needed, and, for real images, some form of video projection technique must be used.

Projection CRT. One long-used technique for showing large screen video pictures is to use a high-brightness CRT and an optical system to project it on a screen. The current

TABLE 6

AAH - FWS IMAGE DISPLAY - MATRIX OF POSSIBILITIES

IMAGE DISPLAY TYPE	FIELD OF VIEW - CHANNELS	RESOLUTION	SCENE BRIGHTNESS	LUMINOUS OUTPUT FLUX	COLOR TYPE	AVAILABILITY (SCHEDULE FOR FIRST UNITS)	TECHNOLOGY STATE - FUTURE GROWTH	COST-EFFECTIVENESS ESTIMATE	SPECIAL RESTRICTIONS OR CHARACTERISTICS
...sired characteristic ...r AAH training	$\pm 90^{o}$ azimuth $+ 15\text{-}40^{o}$ elevation	One arc-min.	At least 5 ft. lamberts	Enough to give desired scene brightness	Full color	Available in mid 1979	Low risk-high growth potential	Benefit/cost ratio high	No special restrictions
...rtual Image									
Mirror/Beamsplitter	$\pm 25^{o}$ AZ per $\pm 20^{o}$ EL channel Difficult to abut channels	3 arc-min.	15-20 ft.-lamberts	80 lumens CRT	Simultaneous color	Available now	High maturity, low risk-low growth potential	Moderate-high	Forces a two-cockpit configuration. Good for single observers only - hard to mate for multichannel display. Relatively simple and light.
In-line infinity optics (pancake window)	$\pm 45^{o}$ circular inscribed pentagon to butt for multi-channel	5-6 arc-min.	About 1 ft. lambert	Requires 100 lumens or more	Simultaneous color	Available now	Medium maturity and risk - good growth potential	Moderate	Forces a two-cockpit configuration. Good for single observers only. Can be mosaicked for large fields but scene is imperfect across channel edges.
...al Image (projector/screen)									
Film projector	Unrestricted for multiple channels	One arc-min.	15-20 ft. lamberts	3000 lumens	Color film	Available now	High maturity, low risk-medium growth potential	Moderate	Very high resolution - low cost, but no control over filmed flight path.
Projection CRT/screen	Unrestricted for multiple channels	3 minutes	3.3 ft. lamberts	500 lumens	Simultaneous color	Available now	Technology mature, medium risk, low potential	Low	No tilt restrictions - CRT life short for high outputs
Eidophor projector/screen	Unrestricted for multiple channels	3 minutes	25	7000 lumens 900	Simultaneous color or field sequential color	Available now	Technology mature, low risk - little potential	Low	Very large and heavy - cannot be mounted on motion platform due to tilt and oil film restrictions. High operating/maintenance costs.
GE light valve/screen	Unrestricted for multiple channels	3 minutes	6.67	1000 lumens	Simultaneous color	Available now	Technology mature-low risk-medium potential	High	Limited in tilt. But can be mounted on motion platforms. ± 45° pitch and roll (cyclic).
Liquid crystal projector/screen	Unrestricted for multiple channels	3 minutes	4.6	1600 lumens	Simultaneous color	800 lumen monochrome available now, 1600 lumen color scheduled for 1979	Technology developing-medium risk-high potential	High	Relatively small and light-weight. No tilt restrictions. Operation and maintenance costs low.

TABLE 6 (cont'd)

AAH - FWS IMAGE DISPLAY - MATRIX OF POSSIBILITIES

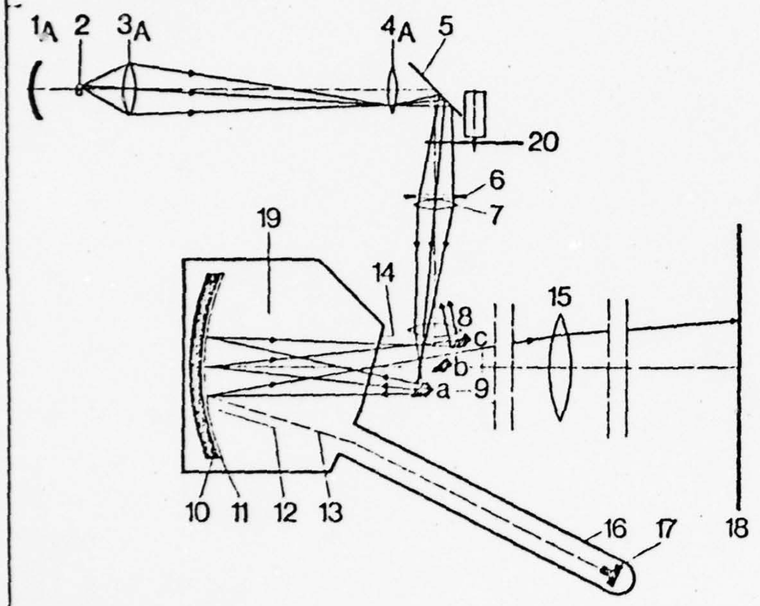
IMAGE DISPLAY TYPE	FIELD OF VIEW - CHANNELS	RESOLUTION	SCENE BRIGHTNESS	LUMINOUS OUTPUT FLUX	COLOR TYPE	AVAILABILITY (SCHEDULE FOR FIRST UNITS)	TECHNOLOGY STATE - FUTURE GROWTH	COST-EFFECTIVENESS ESTIMATE	SPECIAL RESTRICTIONS OR CHARACTERISTICS
Laser scanning projector/screen	175° AZ single channel $+20^\circ$ - 40° EL	7 minutes	10 ft. lamberts	430 lumens	Simultaneous color	Breadboard unit scheduled for late 1978	Feasibility study done. Breadboard model in development, high risk-high potential	Moderate	
360° projector/screen	360° AZ $+20$-40° EL 12 channel	9 minutes	10 ft. lamberts	Unknown	Simultaneous color	Feasibility model scheduled for late 1978	Initial development and breadboard effort underway at NTEC. Very high risk-high potential	Unknown	

Advent commercial and home projectors are an example of this type. Projection CRTs have been limited by inability to make a reasonably bright display for large screens without such exotic techniques as sapphire faceplates and high voltages, with resulting problems with cooling, life, and replacement cost. Philips, Aydin and Aeronutronic-Ford, among others, have produced large-screen display projection systems using CRTs.

Light Valves. Instead of trying to obtain enough light from a phosphor, several light valve techniques have been developed and are being successfully used for the largest video displays in existence. The light valve uses the TV video to control the output of a high-brightness continuous light source such as a xenon arc lamp. In these equipments, black levels in the video cause the incoming arc lamp light to be reflected back to the lamp, while the white video changes the lamp light so that it is sent out through projection optics to a screen. We will discuss three forms of light valve which might be applied to the AAH-FWS.

Eidophor. The Eidophor video projector is a Swiss-made device that uses an oil film which is written on by an electron gun as its light valve. Figure 20 shows a sketch of the Eidophor principle. A xenon arc lamp light source is directed to a rotating mirror through a Schlieren mirror bar optical system. A special oil film covers the mirror. Where the electron gun has written a TV line on the oil, the hills and valleys produced in the film by the non-black elements cause the reflected light to pass through the bars of the Schlieren mirror and are imaged on the screen by the projection lens. Black elements do not disturb the oil film and the reflected light hits the mirror bars and is returned to the light source.

EIDOPHOR PRINCIPLE



1 A	AUXILIARY SPHERICAL MIRROR
2	EXTREME POINT OF THE LIGHT SOURCE
3 A	CONDENSER LENS
4 A	CORRECTION LENS
5	COLD MIRROR
6	PICTURE WINDOW
7	CONVERGING LENS
8	FIELD LENS
9 a,b,c	BAR SYSTEM
10	SPHERICAL MIRROR
11	CONTROL LAYER
12	PERTURBATION IN THE OIL LAYER
13	ELECTRON BEAM
14	CLOSING WINDOW
15	OBJECTIVE LENS
16	ELECTRON GUN
17	CATHODE
18	SCREEN
19	VACUUM CHAMBER
20	COLOUR WHEEL

Black and White or
Sequential Colour EIDOPHOR

FIGURE 20. EIDOPHOR PRINCIPLE

Eidophor projectors are produced in black and white, field sequential color, and simultaneous color models. They are characterized by very high brightness and thus are used for the largest display scenes. Their drawback is their large size and heavy weight, and high operating and maintenance costs.

GE Light Valve. Another version of the deformable oil film light valve is the GE projector. Packaged as a sealed replacement assembly instead of containing replaceable components as in the Eidophor, GE obtains full color from a single electron gun, oil control layer, and optical axis. This is done by writing simultaneously on three sets of diffraction gratings which determine color intensity in conjunction with input and output spatial filters. The sealed light valve contains the electron gun, focus deflection system, fluid control layer, fluid reservoir and filter, and an ion vacumn pump. The tubes have a 2000 to 3000-hour operating life.

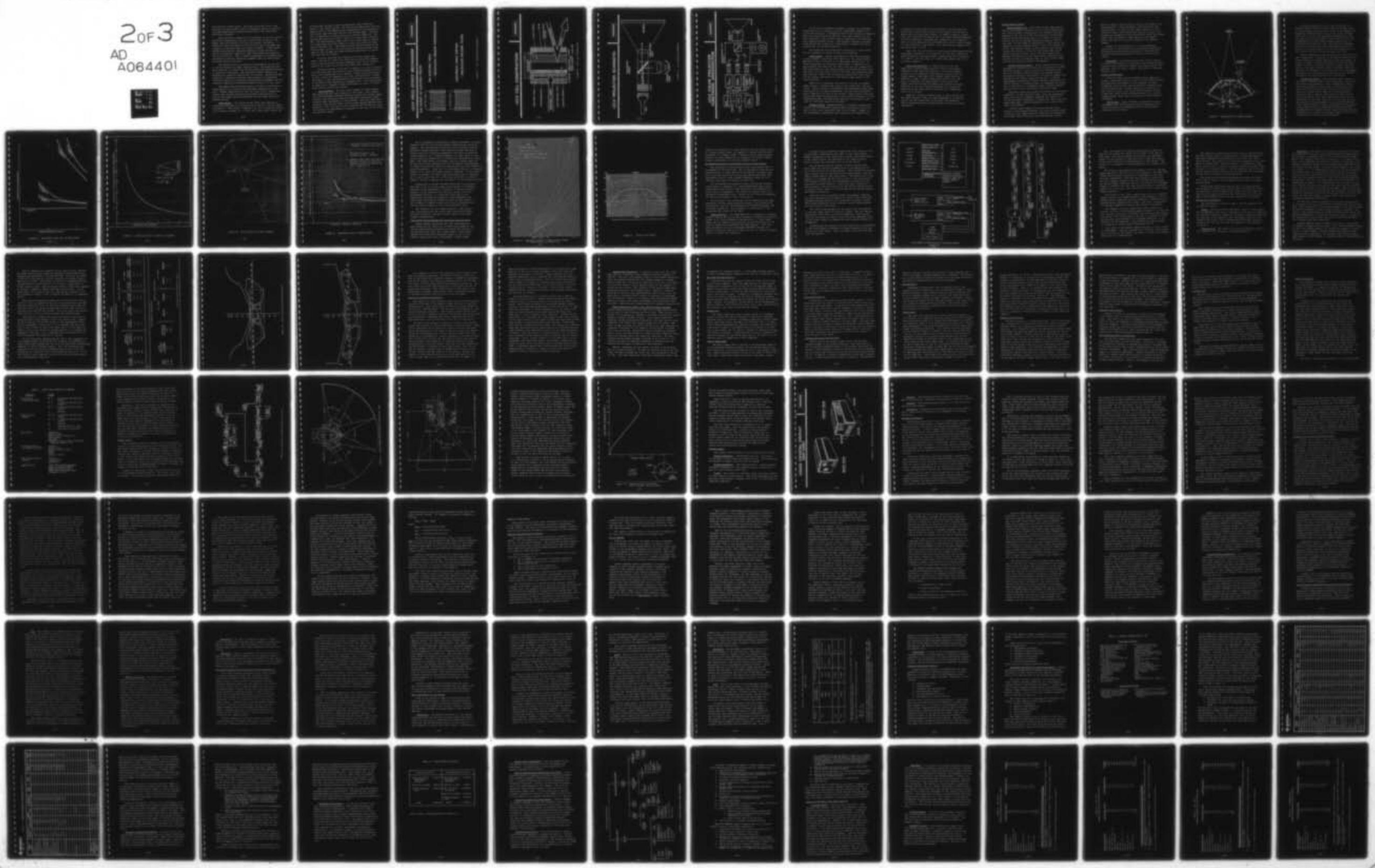
GE is currently developing a high line rate, high brightness version of their light valve projector which can be applied to the AAHT display. This projector will output 1000 lumens and work at 1000 scan line video rates. Expected to weigh about 130 pounds, it is light enough to be mounted on a motion platform whose motions are reasonably cyclic. With a proven and mature technology, the GE display projectors have good potential for an AAHT display.

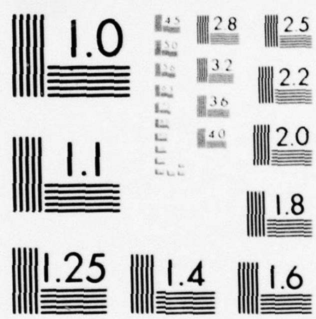
Liquid Crystal Light Valve (LCLV) Video Projector. Since 1970, Hughes Aircraft has been developing a projection technique using a liquid crystal light valve. Hughes has recently demonstrated a monochrome projector that has excellent promise for large screen displays and will have good reliability and low operating costs.

Availability. The hybrid field effect liquid crystal light valve (LCLV) is a product of fundamental research and subsequent directed development activities at Hughes Research Laboratories

AD-A064 401 SPERRY SECOR FAIRFAX VA F/G 14/2
AH-64 FLIGHT AND WEAPONS SIMULATOR CONCEPT FORMULATION STUDY. V--ETC(U)
SEP 77 J L DICKMAN, H KESTENBAUM, P W CARO N61339-77-C-0048
UNCLASSIFIED SE-622-CFS-114-VOL-2 NL

2 OF 3
AD
A064401





MICROCOPY RESOLUTION TEST CHART

over the past several years. This thin film device uses a combination of twisted nematic and bi-refringence effects to produce the light amplification properties achieved by the constituent multi-layer assembly.

With successful completion of development of the basic device, production responsibility has been transitioned recently to the Hughes Industrial Products Division at Carlsbad, California. A production type environment for the LCLV has been established and a number of cells have been successfully produced. A Navy-funded Manufacturing Methods Technology program is being utilized to assist in achieving a high rate, high yield production capability for the LCLV device. This is being accomplished by utilizing batch operations on special, dedicated equipment under controlled manufacturing process conditions.

The responsibility for application development for the LCLV is divided between two Hughes organizations: the Industrial Products Division at Carlsbad and the Data Processing Products Division at Fullerton, California. The Industrial Products Division is pursuing all commercial applications of the LCLV. During 1976 they completed a laboratory prototype color projector for broadcast television which was successfully demonstrated in December, and are currently completing an engineering model projector of this type.

The Hughes Data Processing Products Division at Fullerton is responsible for all military and government applications of the LCLV. Primary applications to date are large screen, command and control type displays and training simulator applications for both virtual image optically-mosaicked and real image projection display systems.

Basic Theory. The liquid crystal light valve operates by tilting the molecules in a crystal with an electric field as shown in Figure 21. This effect is applied in a cell of sandwich construction as shown in Figure 22. A fiber optic input layer carries the

writing light through a light blocking layer and a dielectric mirror to the liquid crystal. The projection light enters from the opposite side of the sandwich and is polarized by the molecules of the crystal that have been tilted by the writing light. The LCLV cell is applied in a video projector as shown in Figure 23. The writing end fiber optic input is mated to a fiber optic faceplate CRT. The high intensity light input from a xenon lamp is carried to a polarizing prism that deflects it into the projection input side of the LCLV cell. The change in polarization induced by the writing light action on the cell allows the reflected xenon lamp light to pass through the polarizing/analyzing prism to a projection lens and on a screen.

It can be seen that the components are few, simple, and fixed. The use of a CRT as the input device avoids the complexities of vacuum systems and major components that can be contaminated by oil films, as in fluid film light valve projectors.

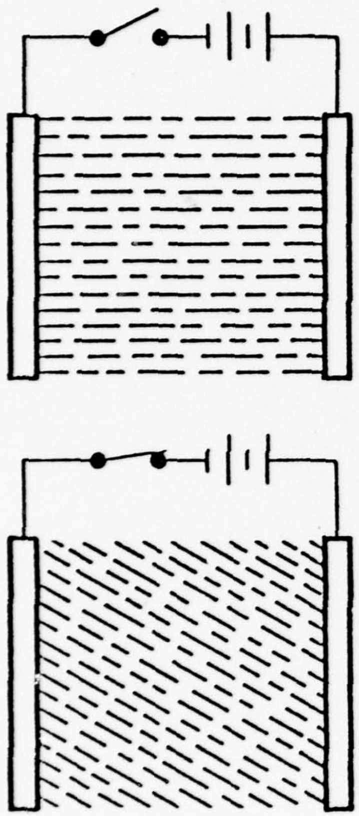
The basic concept of the LCLV is applied to a color projector by using three CRTs and LCLV cells, and combining dichroics to produce a full simultaneous color display. Figure 24 shows how this is done. Since all components are static and mounted on a common base plate, a test pattern/projection distortion correction memory is included to make registration alignment easy. Once registration is done, only a component change can disturb it, and it is easily reset with the stored test pattern.

Line Standards. The basic line standard for which Hughes LCLV projectors have been designed is 1023 lines. This includes the initial HDP-800 breadboard projector (which was recently demonstrated), the definition study and subsequent feasibility demonstration model development of the 3-channel, full-color ASPT type projector under Project 1958, and the single-channel HDP-2000 type projector. The 1023 lines is at an expected MTF (modulation transfer function) of approximately 30 percent in the case of the latter two projector types.

LCLV FIELD EFFECT MECHANISM

HUGHES

THE EFFECT OF ELECTRIC FIELDS



NO ELECTRIC FIELD

— MOLECULES REMAIN PERPENDICULAR

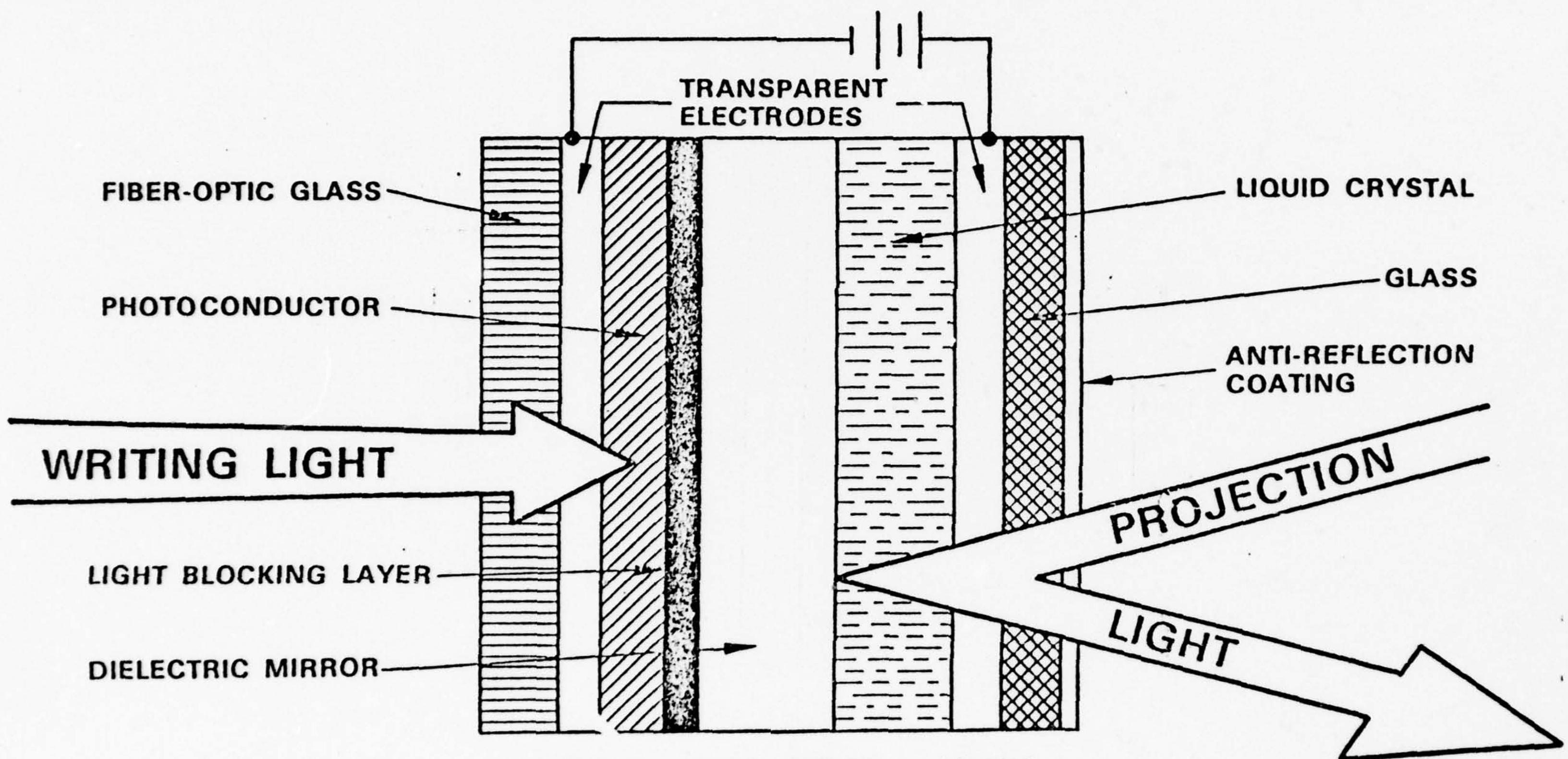
ELECTRICAL FIELD APPLIED

— MOLECULES BECOME TILTED

FIGURE 21. LCLV FIELD EFFECT MECHANISM

LCLV CELL CONSTRUCTION

HUGHES



THICKNESS: FIBER OPTICS — 12 MM
GLASS — 12 MM
LIQUID CRYSTAL — 0.006 MM

FIGURE 22. LCLV CELL CONSTRUCTION

LCLV PROJECTOR SCHEMATIC

HUGHES

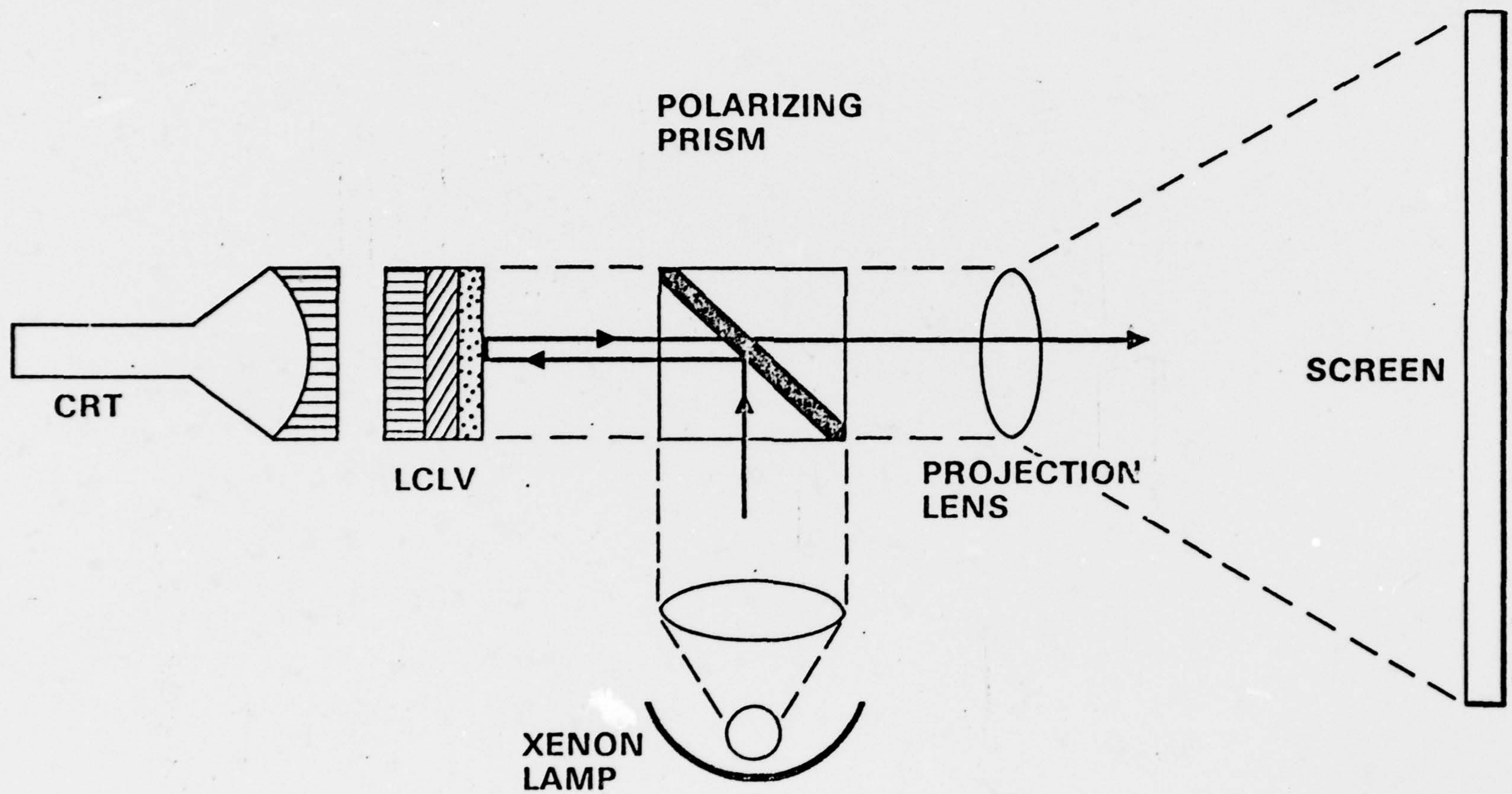


FIGURE 23. LCLV PROJECTOR SCHEMATIC

LCLV COLOR PROJECTOR FUNCTIONAL ORGANIZATION

HUGHES

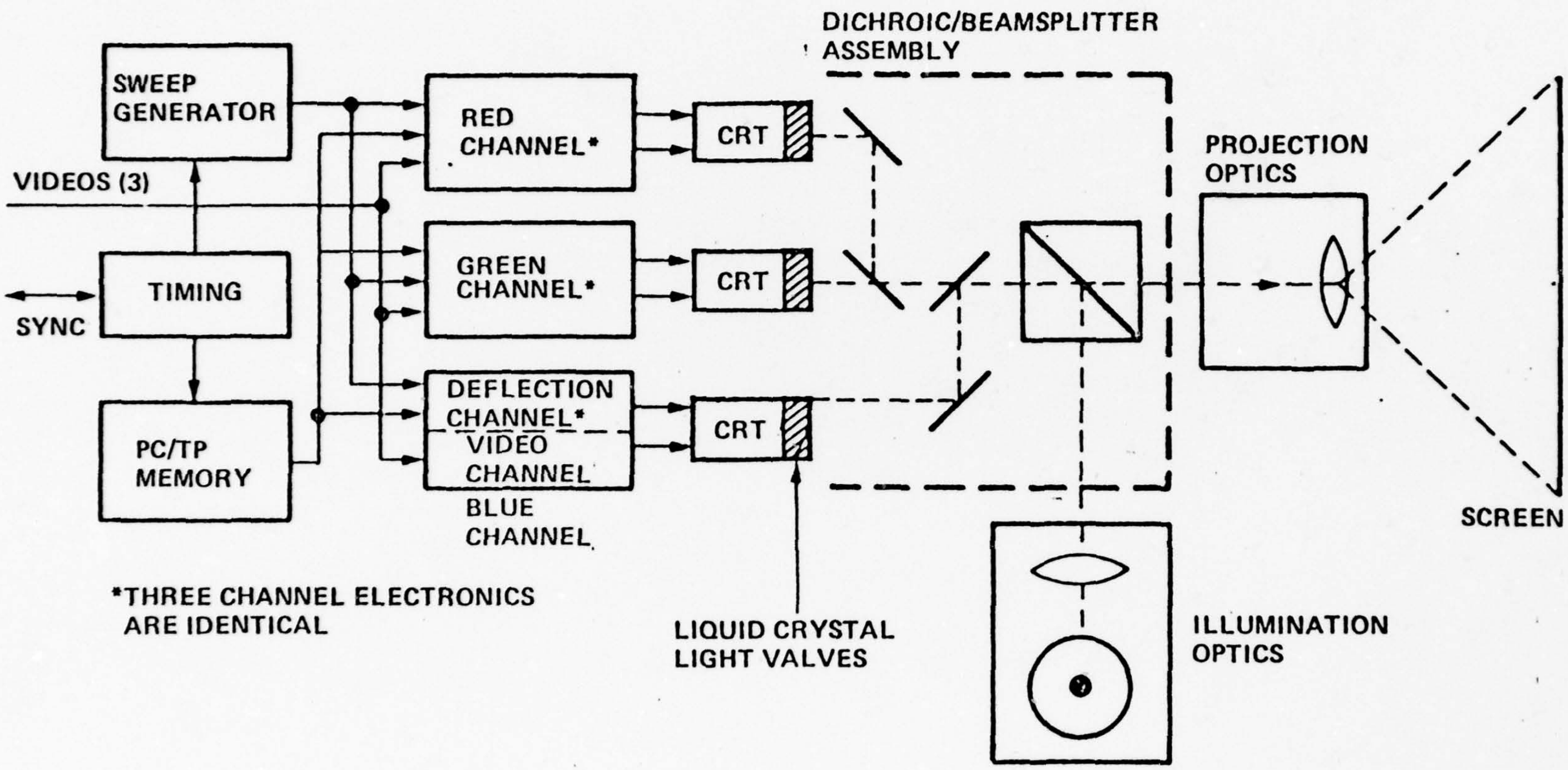


FIGURE 24. LCLV COLOR PROJECTOR FUNCTIONAL ORGANIZATION

Activities are underway at Hughes to improve the achievable resolution so as to increase the line standard/MTF capabilities of the LCLV projector. Development efforts are underway and improvements are being achieved in CRT spot size, LCLV resolution, and LCLV sensitivity - all of which lead to improvement in achievable line standards and MTF values. Some simulator programs currently being defined will require the achievements of higher resolution capabilities for the LCLV projector.

The projectors are designed for flexibility of input format and are configured to accept several line standards.

Light Output. Current developments of the LCLV projectors of the 3-channel, full-color ASPT type and of the single-channel HDP-2000 utilize 1.6 kw and 1.0 kw lamp power respectively. At these lamp powers the achievable light output is expected to be approximately 300 lumens for the full-color case and somewhat less than 2000 lumens for the single-channel (non-monochrome) projector. The dichroic filters used to obtain the three color primaries together with the "tuned" (for the spectral region) LCLV color cells are the primary contributors to the reduced light output of the color projector.

There are no conceptual limitations to the use of brighter light sources to increase the output of the light-valve type projector. While testing or development work using higher power light sources has not yet been accomplished, this has been anticipated and is expected to be done in the future. Light output of the projector would then be proportional to the increased intensity in the illuminating beam. No significant problems in achieving a color output of 1000-1500 lumens are foreseen.

Present Status. Hughes-Fullerton is currently completing a contract for four HDP-2000 single-channel (monochrome) projectors with the first unit completing final test in August. Hughes is also designing a simultaneous color projector for simulator use.

A feasibility study under Air Force Contract 1958 has been completed and a final report should soon be issued. For the past 5 months they have been under contract to AFHRL to produce a prototype color projector for application to the ASPT (Advanced Simulator For Pilot Training) at Williams AFB. Hughes has just completed their critical design review with AFHRL and is now in detail design for this projector. They expect to be operating the complete LCLV projector early in 1978.

Thus, the color projector is a well-established program nearing development completion. Its potential for low cost, simplicity, high reliability, and light weight, coupled with basic resolution of 1,600 TV lines and outputs of 1,000-1,500 lumens, make it an excellent prospect.

Laser Scan Projector. In conjunction with the wide angle laser scanning image generator, NTEC is developing a compatible laser scan video projector to match the characteristics of the generator. This projector would accept the single channel, wide angle (175° azimuth) video from the generator, either a laser-scanned model board or CGI, and use it to modulate the output beams to two or more gas lasers, which would then be combined and scanned in a manner identical to the laser scanning technique for viewing the model board. The scene would be projected on a wraparound screen to be viewed.

Identical technical problems apply to the projector and the image generator. Thus, the same reasoning on its application to the AAH trainer must be followed: the technique must be demonstrated and evaluated before it can be seriously considered.

Virtual Image Displays

Mirror/Beamsplitter. The common virtual image display used in most flight simulators is of the mirror/beamsplitter type. This utilizes a curved mirror to collimate the image produced on the face of a CRT. The partially silvered beamsplitter allows the optical axis to be folded so that the observer can see the infinity-projected image on a direct axis while the CRT image is reflected 90° to the mirror. The simplicity of these displays leads to low costs, good reliability, and adequate fields of view. However, the viewing volume of the mirror is such that the proper image can be seen by only one observer. Also, with the folded optics, physical limitations are such that multiple displays cannot be mated to form a continuous image. At best, distinct gaps are left when multiple displays are abutted.

In-Line Infinity Optics. In-line infinity optics were developed to overcome the problem of mating multiple channel infinity displays to form a continuous, wide-angle scene. With this display, commonly known as the pancake window, developed by Farrand, the observer, the optical elements and the CRT are all along a single optical axis. A complex arrangement of polarizers, fresnel elements, and mirrors are used to achieve a collimated image. By arranging the periphery of the window in a pentagonal shape, multiple displays can be mated to form a continuous, wide-field image.

The major limitation, besides increased cost and optical complexity, is that extensive light losses are experienced due to the optical techniques employed. Only about 1% of the CRT faceplate brightness is transmitted. Thus, even with high output CRTs, display brightness is low, usually less than 1 foot-lambert.

The best known example of multiple pancake window display is the Advanced Simulator for Pilot Training (ASPT) at the Air Force Human Resources Laboratory at Williams Air Force Base. This system uses seven huge pancake windows

driven by special 36-inch CRTs in each of two cockpits. The system produces a very wide-angle, large-elevation, monochrome display. In order for the single observer to see a continuous image, each channel must display a picture that overlaps its neighbors so that head motion across the viewing volume will not produce a blank section in one channel before that part of the picture appears in the adjacent channel.

Apropos of maintainability, it was noted during a recent visit to the facility that the pancake windows have deteriorated with time and now produce a relatively dim picture with distracting specks from dirt in the optical system.

Conclusions. The infinity projection optical quality of virtual image displays is pleasing to an observer watching a moving scene. While multi-channel wide angle displays are possible, they are costly, complex, and suited to individual observers only.

Screen Considerations

Since all video projectors display their images on a screen, consideration must be given to screen characteristics and dimensions. The geometry of the display, the image brightness on the screen, and the projector luminous output are all related. For a display which will be observed by more than one viewer, such as in the pilot/gunner trainer, a spherical screen is not suitable because of its limited viewing volume. Thus, flat or cylindrical screens should be considered.

Flat Screen. Figure 25 shows a typical flat screen arrangement with rear projection. This arrangement allows on-axis projection for minimum distortion and provides projection ratio freedom.

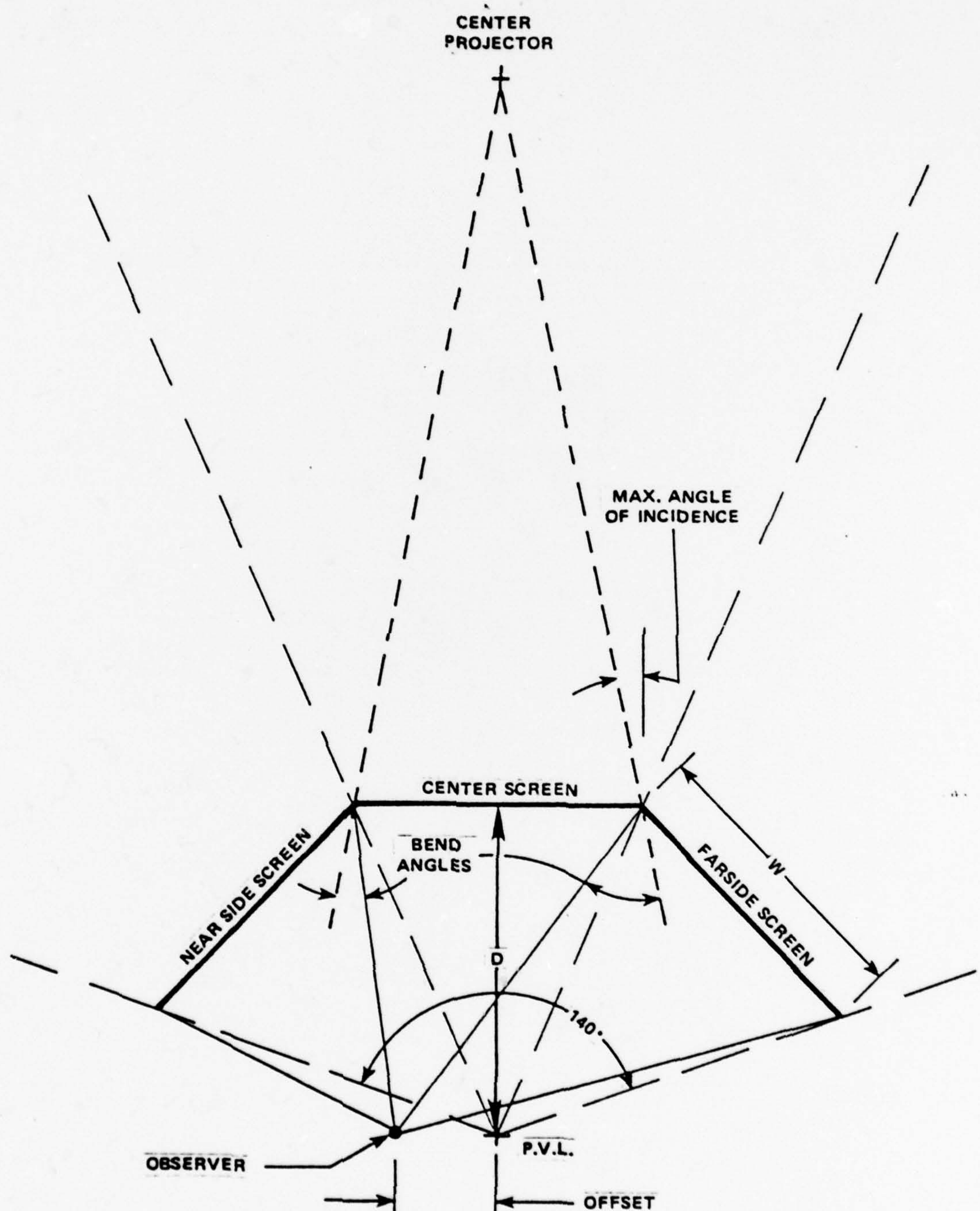


FIGURE 25. REAR PROJECTION SCREEN GEOMETRY

The major problem with rear screen projection for observers offset from the vertex of the screen axes, which is the preferred viewing location (PVL), is the significant brightness difference that occurs at the screen intersections. This is due to the high angular difference of the rays from the two screen edges to the observer's eye. This is emphasized by screen gains of higher than unity, as demonstrated by Figure 26. This shows that the brightness ratios for the three-flat-screen configuration rise well above 4:1 for screen gains of 2.5 for an observer who is 2 feet from the PVL for a screen distance of 10 feet.

Another problem with rear projection on a screen is the space requirement. In addition to the theater area for the cockpit module and screen, additional clear area behind the screen is needed to provide for projector throw distances. Figure 27 shows the relation between the projection ratio, which is the throw distance divided by picture width, and the angle of incidence to the screen edge. This relationship exacerbates the brightness ratio problem as it is reduced, and impacts the space problem as it is increased.

<u>Cylindrical Screen</u>. These problems, while subject to reasonable compromise under some circumstances, cause us to turn toward the cylindrical screen configuration. Front-projected cylindrical screens take up significantly less space because the observer and projectors can be near to each other. Because they cannot be co-located however, projection must be offset, either above or below the observer's location. This causes some distortions, such as keystoning and line sag, which must be corrected, but this has been done very successfully in this kind of installation. Figure 28 shows a typical cylindrical front-projected screen geometry with the same basics as the flat screen configuration for similar offsets. Figure 29 shows that the brightness ratio problem for adjacent scenes is very low for screen gains of the type being considered.

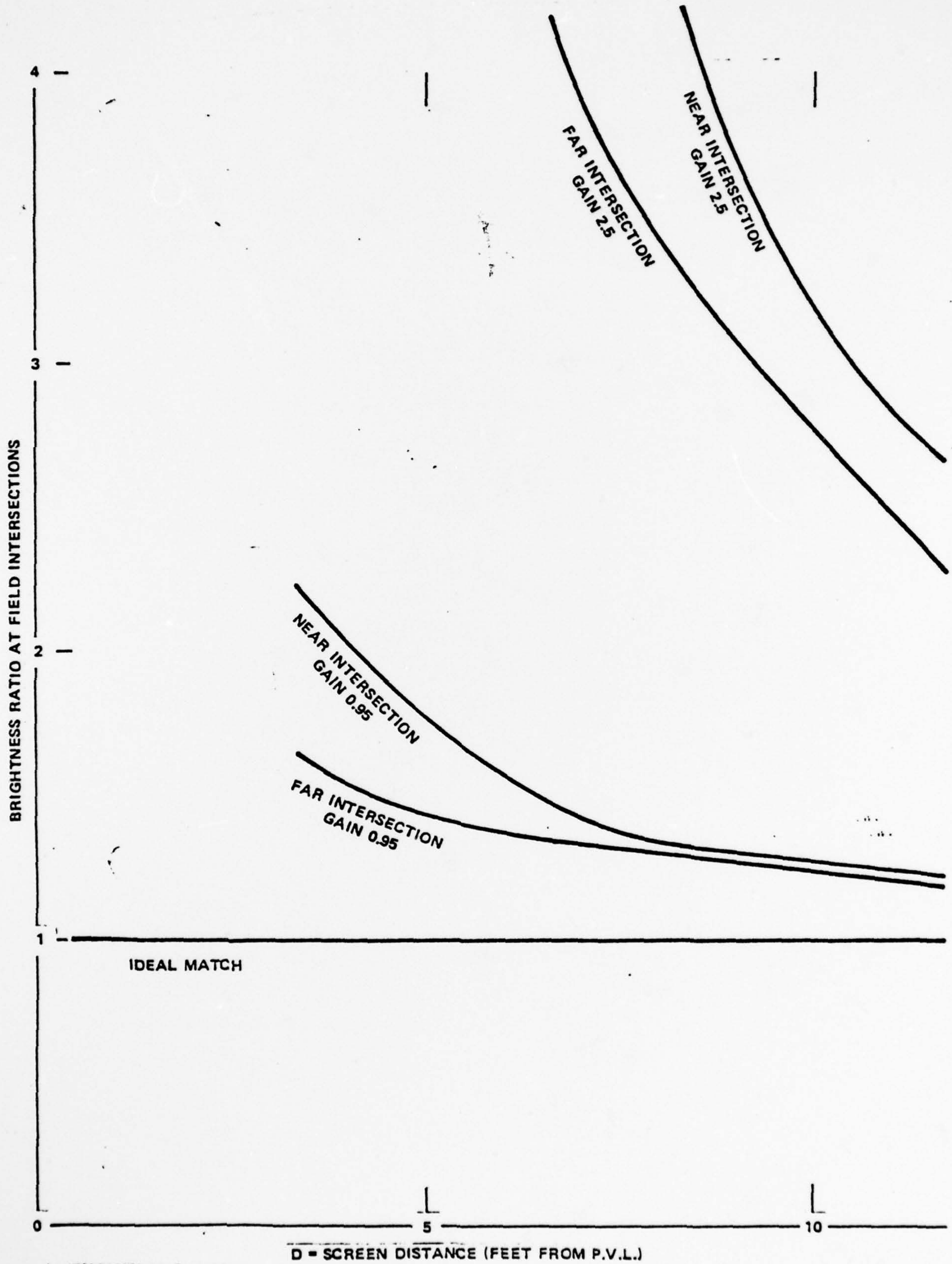


FIGURE 26. BRIGHTNESS RATIO FOR TWO-FOOT OFFSET

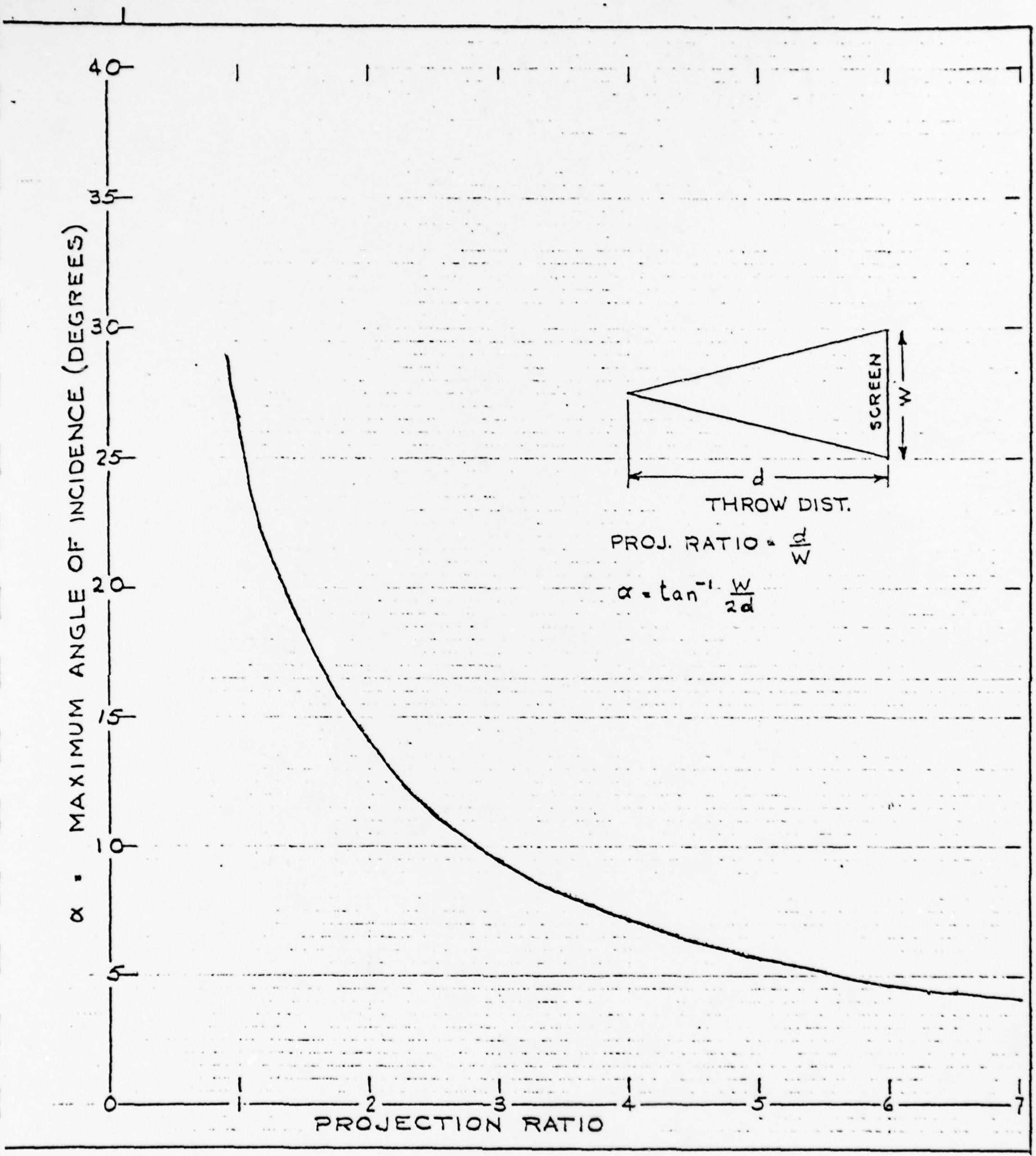


FIGURE 27. PROJECTION RATIO vs ANGLE OF INCIDENCE

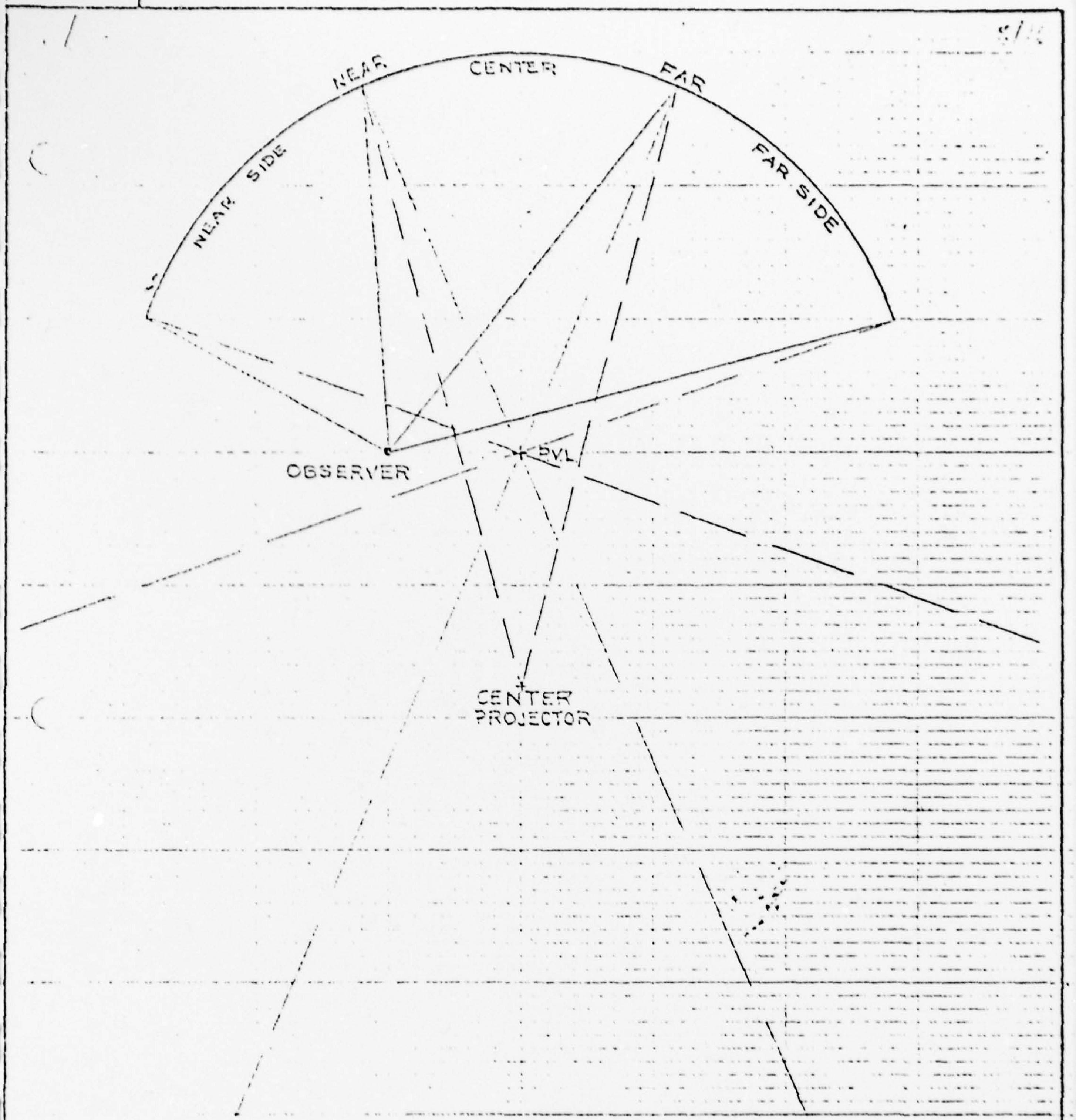


FIGURE 28. FRONT PROJECTION SCREEN GEOMETRY

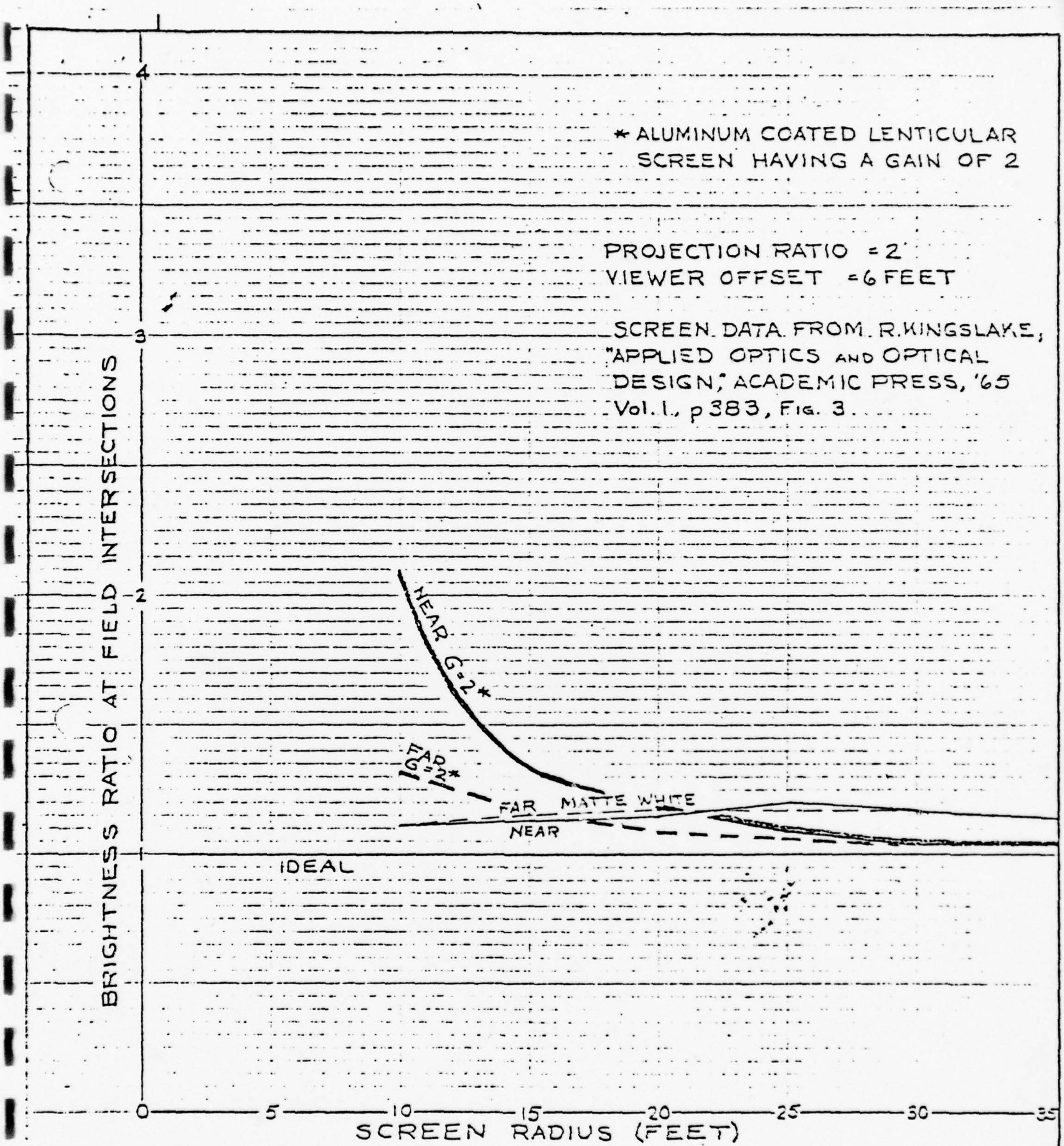


FIGURE 29. BRIGHTNESS RATIO vs SCREEN RADIUS

For a cylindrical configuration, Figure 30 presents a typical tradeoff curve set for various angular dimensions per projector channel. The illustration relates the screen distance from the preferred viewing location to the projector output required to obtain a picture of specific brightness. The curve is drawn for a screen gain of two. Screen brightness is simply equal to projector output per square foot of screen area, multiplied by screen gain. The curve shows, for example, that at a screen radius of 20 feet and picture dimensions of 40 X 30 degress (width/height), 73 lumens of projector output are required for each foot-lambert of picture brightness. Thus, for a 5 foot-lambert picture, a projector capable of at least 365 lumens output is required. If the screen radius is reduced to 15 feet, only 200 lumens would be required. Or, it can be seen that for a 1000 lumen projector, a screen as large as 32 feet in radius will still give a 5 foot-lambert picture.

Screen gain is another variable which must be considered. The ideal is to use a unity gain screen because no brightness variation occurs regardless of projector to observer angles. However, if the observers are relatively fixed, as in the pilot/gunner trainer, it is much more efficient to use screen gain and lower the projector output brightness and input power requirements. Figure 31 shows the gain curves for a number of typical screens that could be considered for various observer angles to the screen projection axis.

The tradeoffs for the display geometry, video projectors, screen gain and size, and cockpit and motion modules are quite sensitive, and have a major impact on the final trainer configuration.

Conclusions and Recommendations Regarding Image Displays

Sperry SECOR's conclusions are that real-image displays should be the choice for the AAHT visual modules. The virtual image methods reviewed (the mirror/beam splitter or the pancake window type) are, respectively, either incompatible with wide field continuous images or are too optically complex and costly. Furthermore, virtual image

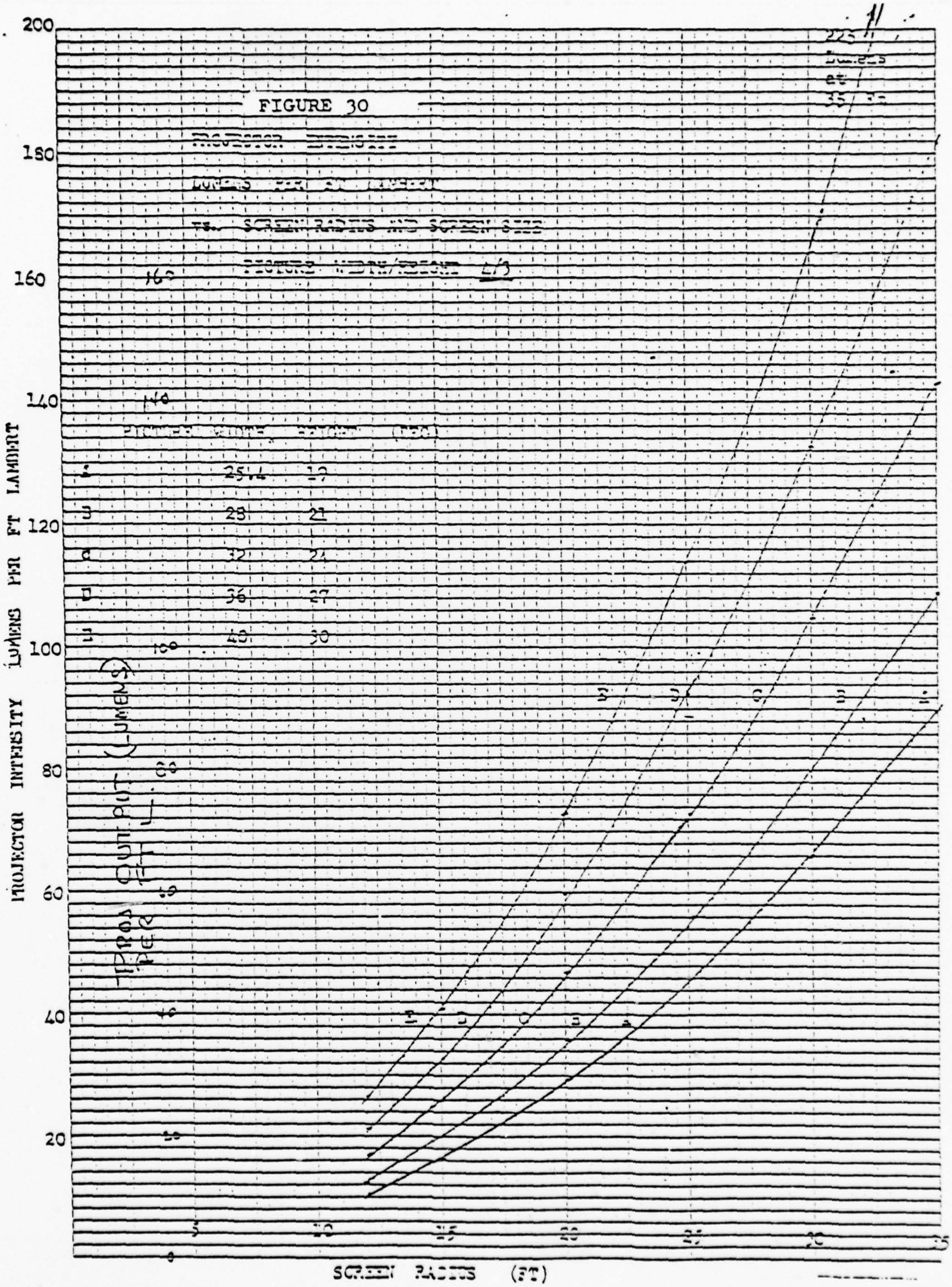
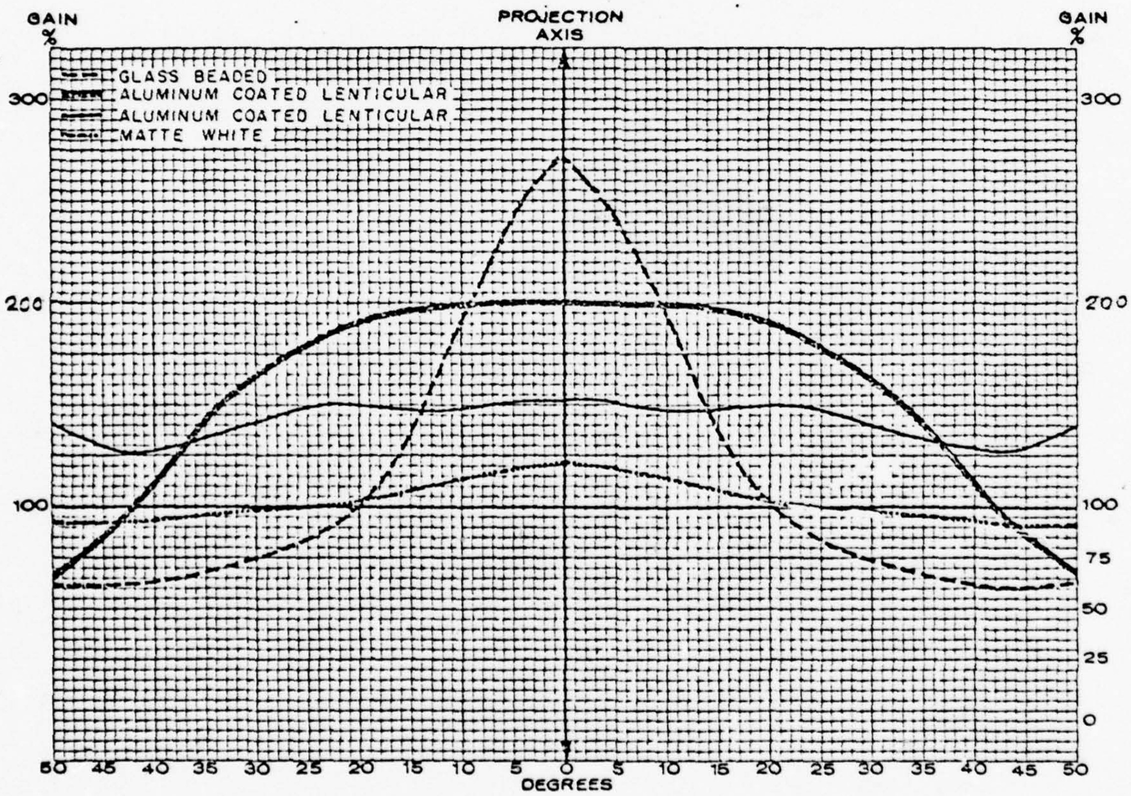


FIGURE 30. PROJECTOR INTENSITY LUMENS PER FT LAMBERT
vs. SCREEN RADIUS AND SCREEN SIZE



Typical gain curves for various screens. Note variation which can be effected in lenticular fabrics.

FIGURE 31. TYPICAL GAIN CURVES

displays are oriented to a single observer and the viewing volume of a single display cannot be expanded to include both the pilot and gunner in a tandem cockpit. Multiple virtual image displays oriented for each crewman are too voluminous to retain a single cockpit configuration for the pilot/gunner trainer.

Recommended Approach to Pilot/Gunner Trainer Visual Module

The following is a description of the visual module that is recommended for the AH-64 FWS. This system derives from the preceding analysis of image generation and display technology, and meets the study objectives of requiring engineering rather than experimental effort, using in-hand technology, using the best technical approaches, and being cost-effective.

The recommended pilot/gunner trainer (the Mission Trainer) visual module is composed of a computer-generated image system, driving both liquid crystal video projectors and simulated aircraft visionics equipments. The projectors display scenes on a cylindrical wraparound screen. Details of the visionics equipments are discussed elsewhere in this study report.

As discussed in the conclusions and recommendations on image generators, CGI was chosen primarily because of its flexibility in providing video for both windshield and TADS/PNVS displays and for threat simulation. The following is a description of the recommended CGI system for the AAHT.

Image Generator. The image generator is composed of a general purpose computer driving two special-purpose CGI pipeline processors. Figure 32 is a block diagram of the generator. As this figure shows, the two channels of processing are required because of the need for simultaneous windshield and TADS displays. Since the pilot and gunner can also interchange TADS/PNVS displays for backup, the picture outputs for these are sent to a video switching matrix to provide this capability.

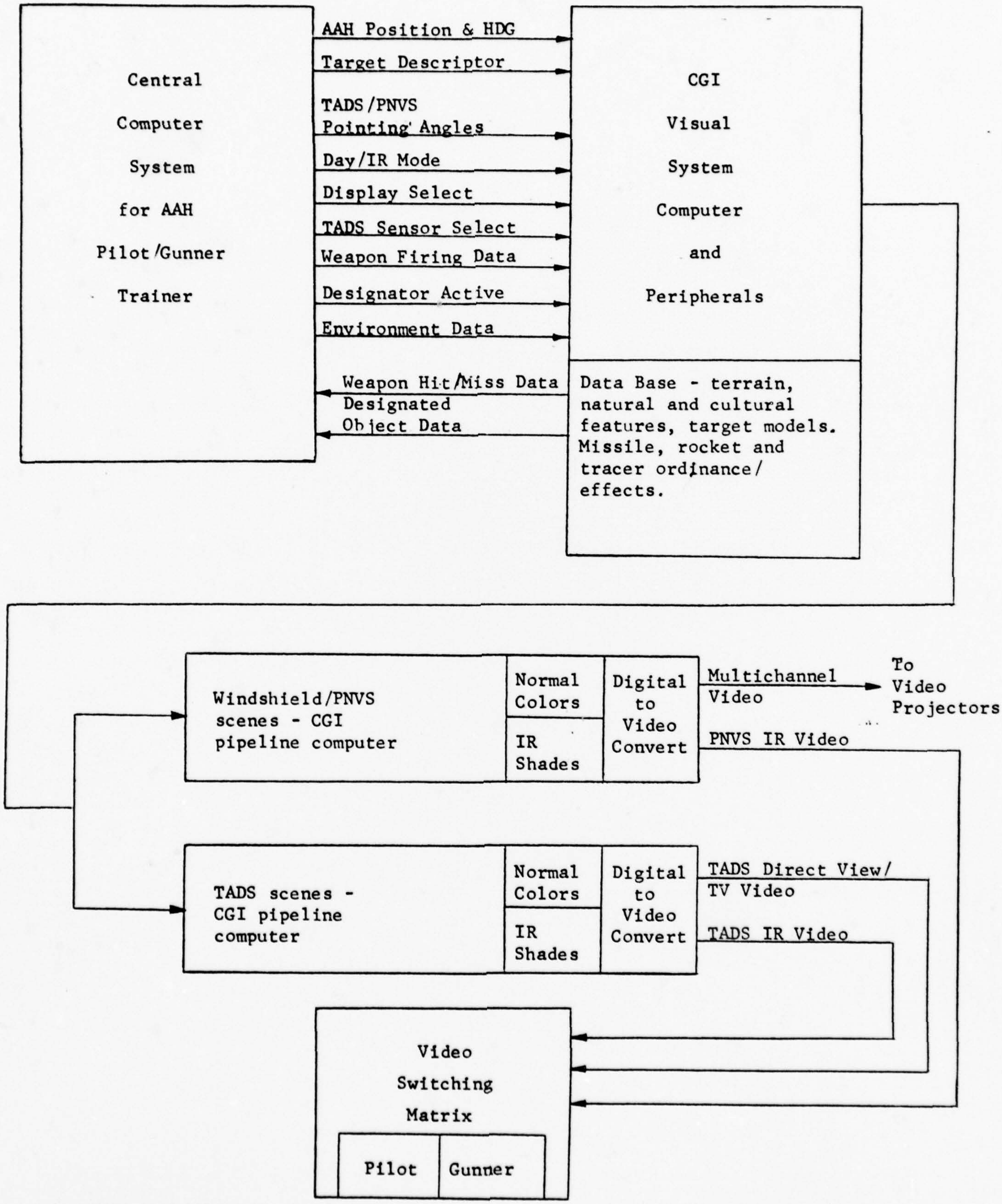
The AAHT central simulation computer has full control of the visual module. Essentially, all inputs to the visual module, whether originated in the instructor's station, the motion system, or the cockpit module, are processed by the computer module. Figure 33 shows the functional flow of the CGI system.

The CGI general purpose computer contains the data base, which comprises a digital representation of the gaming area in the form of vertices of closed polygons. This includes all terrain, static natural and cultural objects, all moving objects, own and other's weapon effects, and scene lights. The primary job of this computer is to manage the data base so that it can call up from the storage disk that part of the gaming area visible from the helicopter's present position. This static data is held in a special memory, together with data on any selected moving objects or weapons effects, where it is acted upon by the special purpose CGI pipeline processors.

From the active environment memory the polygons composing the static and moving scene objects are rotated from a data base storage-coordinate system to an own-aircraft coordinate system. This allows elimination of all backfaces because these polygons are not visible to the viewer.

All front-facing polygons are now passed down the pipeline to the next stage, where the field is clipped. Here all objects outside the final field of view are eliminated, either because they are too distant or above or below the final displayed scene. At this stage, channel assignments for multi-channel display are designated.

Passing down the pipeline, scaling computations are performed so that each polygon is displayed in proper perspective for projection on a flat screen. Also, each edge is provided with edge slope information.



Block Diagram of Visual Module for Pilot/Gunner Trainer

Figure 32

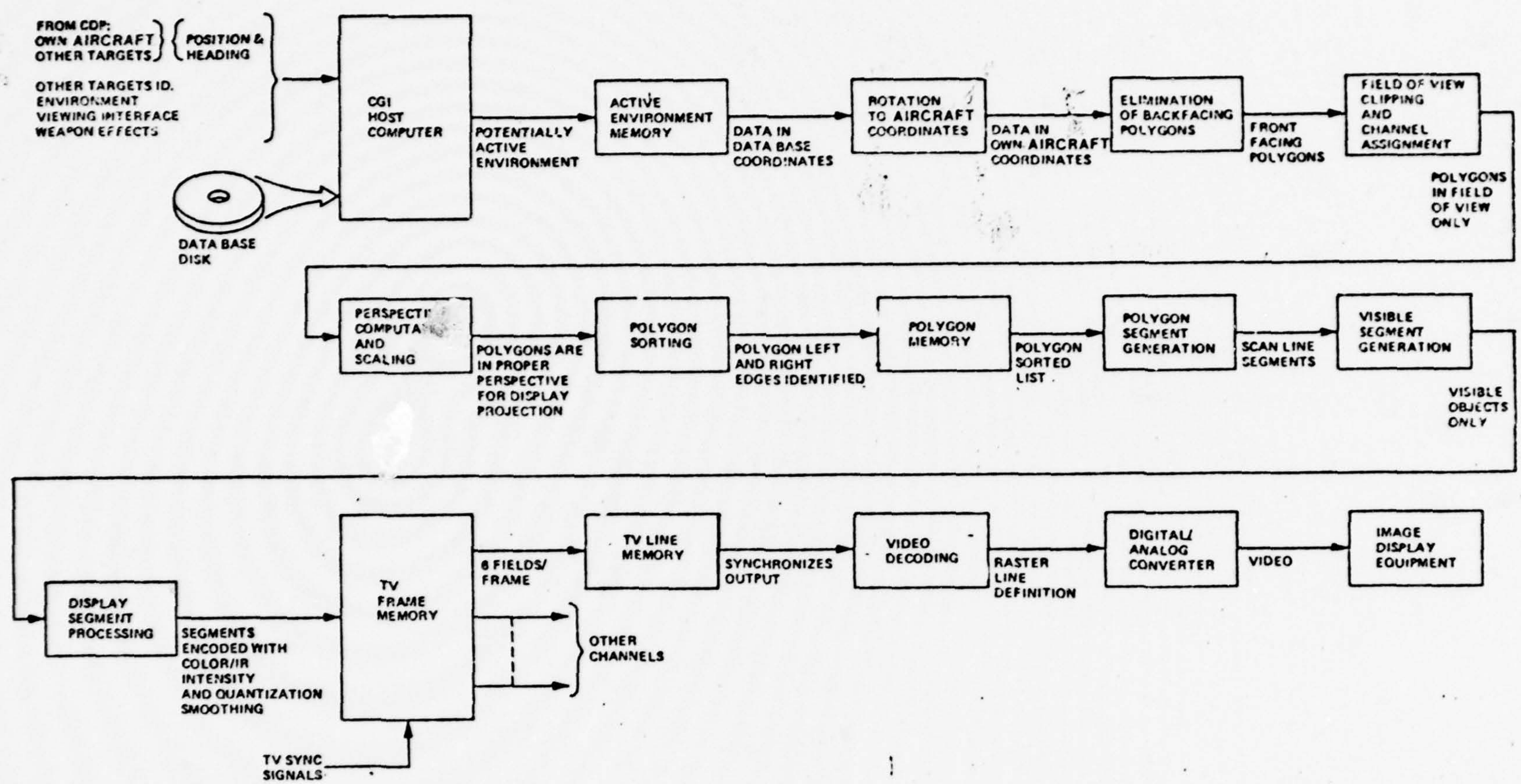


Figure 33. Typical CGI Channel Block Diagram

This is followed by a polygon sorting process, where the edges of each polygon are identified as either a left edge or a right edge. Also in the polygon sorting unit, the upper-most vertex for each polygon is found and used to order all polygons in the scene vertically and horizontally for each channel. The sorted list of polygons is stored temporarily in a polygon buffer memory.

The output of the polygon buffer memory is fed to a polygon segment generator, which acts as a scan converter. The edge slope information previously calculated is transformed to scan line intercept information. Each edge type polygon is converted to scan line segments bounded by the left and right polygon edges. The polygon segment generator creates a sorted list of all polygon segments, ordered by the left edge scan intercept of all polygon segments on a scan line. This ordered list is sent to the visible segment generator.

The purpose of the visible segment generator is to eliminate segments or parts of segments hidden by other segments. This is accomplished by comparing range data wherever a condition of overlapping polygon segments exists along a scan line. That portion of a polygon segment more distant than another is discarded.

The segments, now only representing objects known to be visible, are sent to the display segment processor. For each segment received, the data is reformatted and anti-rastering segments are created. The reformatting of the data is necessary to introduce fog and color information for daylight operations, or IR intensity for IR simulation. Anti-rastering or edge smoothing is introduced to reduce digital quantizing effects.

The output of the display segment processor is fed to a dual TV frame memory. Here the information is stored in a dual buffer and is read out of each buffer, one frame at a time, at a synchronized rate of 30 times/second.

The simulation computer processes the data for own helicopter and other moving objects 30 times/second. The CGI pipelines perform their computations asynchronously, but within the 1/30th second period. Thus, data for a new picture is passed to the frame memory 30 times/second. From that memory, at synchronized video rates, each TV line is read out, decoded, converted to analog video and sent to its display device. The CGI processor that drives the liquid crystal display projectors has an individual TV line memory, decoder and D/A converter for each projector.

The processor driving the TADS displays provides the direct view or day TV video to all the display devices that can present those displays.

During night operations, when the pilot is using the PNVS, and the gunner the FLIR sensor in the TADS, each processor section is converted to insert IR intensities instead of color, and the video line that had been driving the center projector drives the PNVS display (IHADSS), while the other projectors are blanked.

Review of Key Parameters

The following is a review of some of the key parameters for the AAHT CGI system.

Format. The CGI provides simultaneous color TV video outputs. For the TADS/PNVS, the video is specified as 875 line, 30 frames/sec, 2:1 interlace standards. Because of the need to maximize resolution over the wide field windshield view, the highest practical line standards are chosen. Per a standard RS-343A on high resolution closed circuit TV, the 1023 line, 30 frames/sec, 2:1 interlace, is chosen.

Field of View. The field of view for the windshield scene is 180° azimuth by 55° elevation, as discussed earlier.

Resolution. The subjects of resolution and field of view for the windshield view require some further examination and analysis. TV resolution is normally stated as TV lines per picture height. What is left unsaid is that this is based on a 3 x 4 aspect ratio. Thus, if the TADS/PNVS specified line standards are applied to the windshield display, the 875 TV line standard gives about 800 active TV lines per picture height, the others being blanked in the vertical retrace. In a TV camera-monitor chain, the vertical resolution is not 800 lines, but is reduced by the Kell factor, a vertical resolution factor resulting from the interaction of the scanning lines and their spatial relation to the light and dark elements of the picture. This factor has been shown to be about 70% for a TV camera-monitor system. For a CGI-generated picture where the picture elements are placed precisely on the proper line by the generator, the Kell factor is thought not to apply. Thus, the vertical resolution of an 875-line system with CGI should be about 800 lines. Horizontal resolution, unaffected by the Kell factor, is 4/3 x the active lines/picture height, or about 1050 TV lines horizontal, assuming no bandwidth limitations.

The 800-line vertical resolution for the 55° vertical field of view gives just over 4 min/TV line or 8 minutes per optical line pair. Since resolution is a critical parameter in the visual system, it would be desirable to improve these results if possible. Also there is some disagreement over whether the Kell factor can be completely eliminated in a CGI-driven TV display system. At least one CGI manufacturer believes that some kind of factor should apply, but no figures have been determined.

Another important point is whether the field of view should be reduced to enhance the resolution. Since the five-channel display of 180° total azimuth produces 36° azimuth per channel, no reason exists to reduce azimuth. Elevation reduction, however, would improve vertical resolution. For example, a 40° elevation angle would improve the 800 TVL/PH to 3 arcminutes/TVL or 6 minutes/optical line pair.

Table 7 examines the tradeoffs for all these factors together. The table shows vertical resolution figures for three high TV line standards per EIA RS-343: 875, 945 and 1023. For each, the number of active TV lines and the vertical resolution are shown, using a Kell factor of 0.85. This factor is chosen as a compromise between the Kell factor of unity and that of .7, which is applicable to normal camera systems. While we think a factor of near unity applies, no specific evidence to support this has been uncovered. On the other hand, 0.7 is much too low for a CGI system, therefore .85 is put forward as a figure to use to observe the effect of a compromise factor.

The resolution figures are shown for both 55° and 40° vertical fields of view, in minutes/TV line and in minutes/optical line pair. The table shows that if we use 1023 line standards, and accept the 0.85 Kell factor, we obtain an improvement of near 20% in vertical resolution over the 875 line system. If we also reduce the vertical field from 55° to 40° we obtain an additional 20% improvement.

The question is whether the improved resolution justifies reducing the pilot's and gunner's view of the visual scene. Figures 34 and 35 show the 55° and 40° fields of view superimposed on the pilot's and gunner's vision plots. It is apparent that the reduction of their fields of view is not great, but it occurs where the field of view in the trainer is already marginal, i.e., upward and downward to the sides. It is considered that the maximum field of view is paramount and should not be reduced.

On the other hand, implementing the 1023 TV line standards for the windshield while retaining the 875 standards for TADS/PNVS requires only proper scaling plus the use of an additional synchronizing generator in the CGI display channel. Thus, the windshield view system will use the 1023 line standards and will have a vertical resolution of 4 minutes/TV line or 8 min/optical line pair. If the Kell factor of unity applies, the vertical resolution would improve to 7 minutes/optical line pair.

TABLE 7

AAHT RESOLUTION

TV DISPLAY (WINDSHIELD)

			VERTICAL RESOLUTION					
			55° ANGLE			40° ANGLE		
TV LINE STANDARD	ACTIVE LINES	VERTICAL RESOLUTION (0.85 KELL.) TVL/PH	MIN/TVL 1.0 KELL.	MIN/TVL 0.85 KELL.	MIN/OLP 0.85 KELL.	MIN/TVL 1.0 KELL.	MIN/TVL 0.85 KELL.	MIN/OLP 0.85 KELL
875	809	690	4.1	4.8	9.6	3.0	3.5	7.0
945	874	740	3.8	4.5	9.0	2.8	3.2	6.4
1023	946	800	3.5	4.1	8.2	2.5	3.0	6.0

CINE DISPLAY (WINDSHIELD)

			VERTICAL RESOLUTION*			
			55° ANGLE		44° ANGLE	
FILM SIZE	FILM RESOLUTION IN LINE PAIRS/MM	EQUIVALENT IN TVL/PH	MIN/TVL	MIN/OLP	MIN/TVL	MIN/OLP
35 MM	55	1680	2	4	1.5	3
70 MM	55	3400	1	2	0.7	1.4

*No kell factor applies in film.

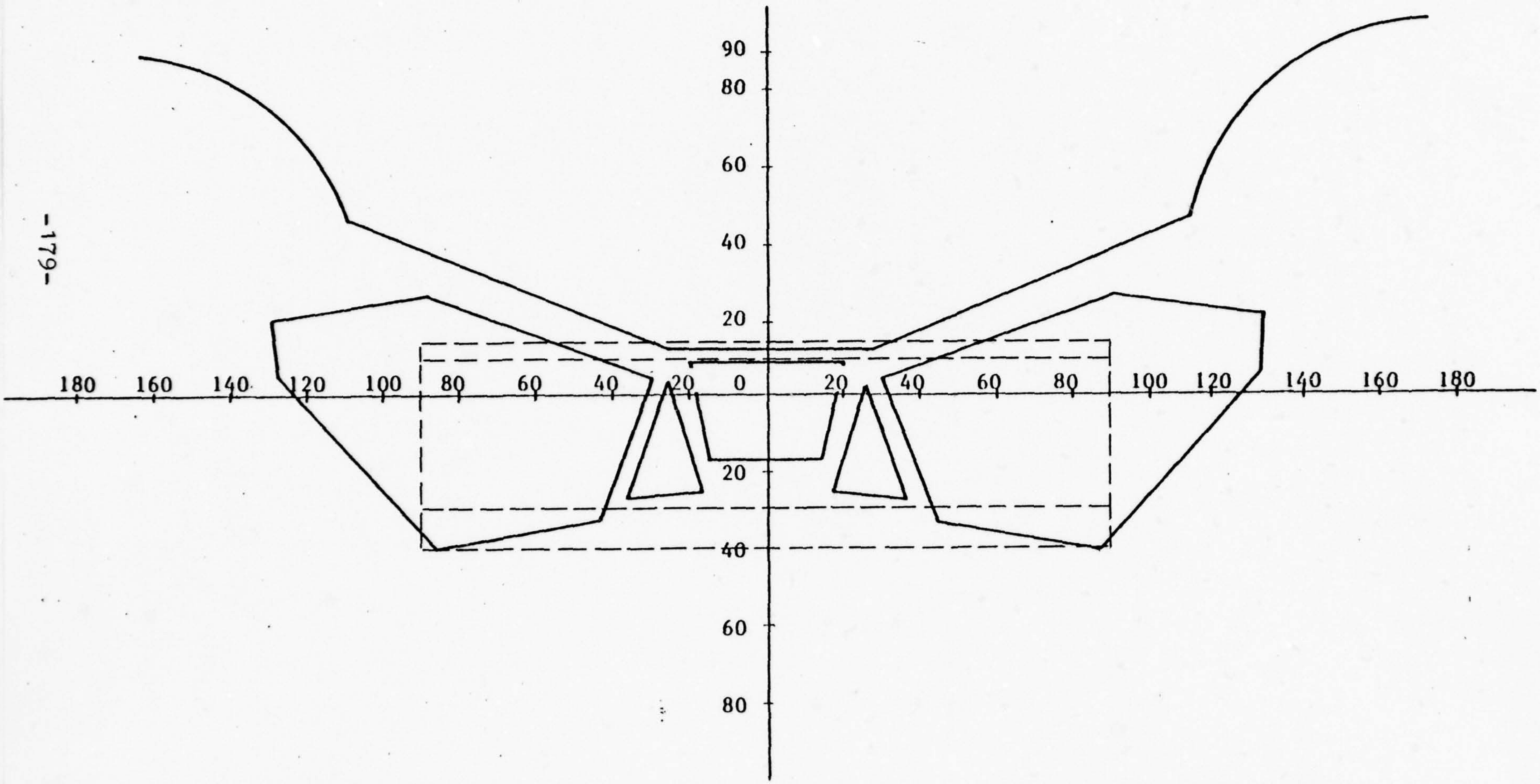


Figure 34. 40°/55° FOV versus Pilot Vision Plot

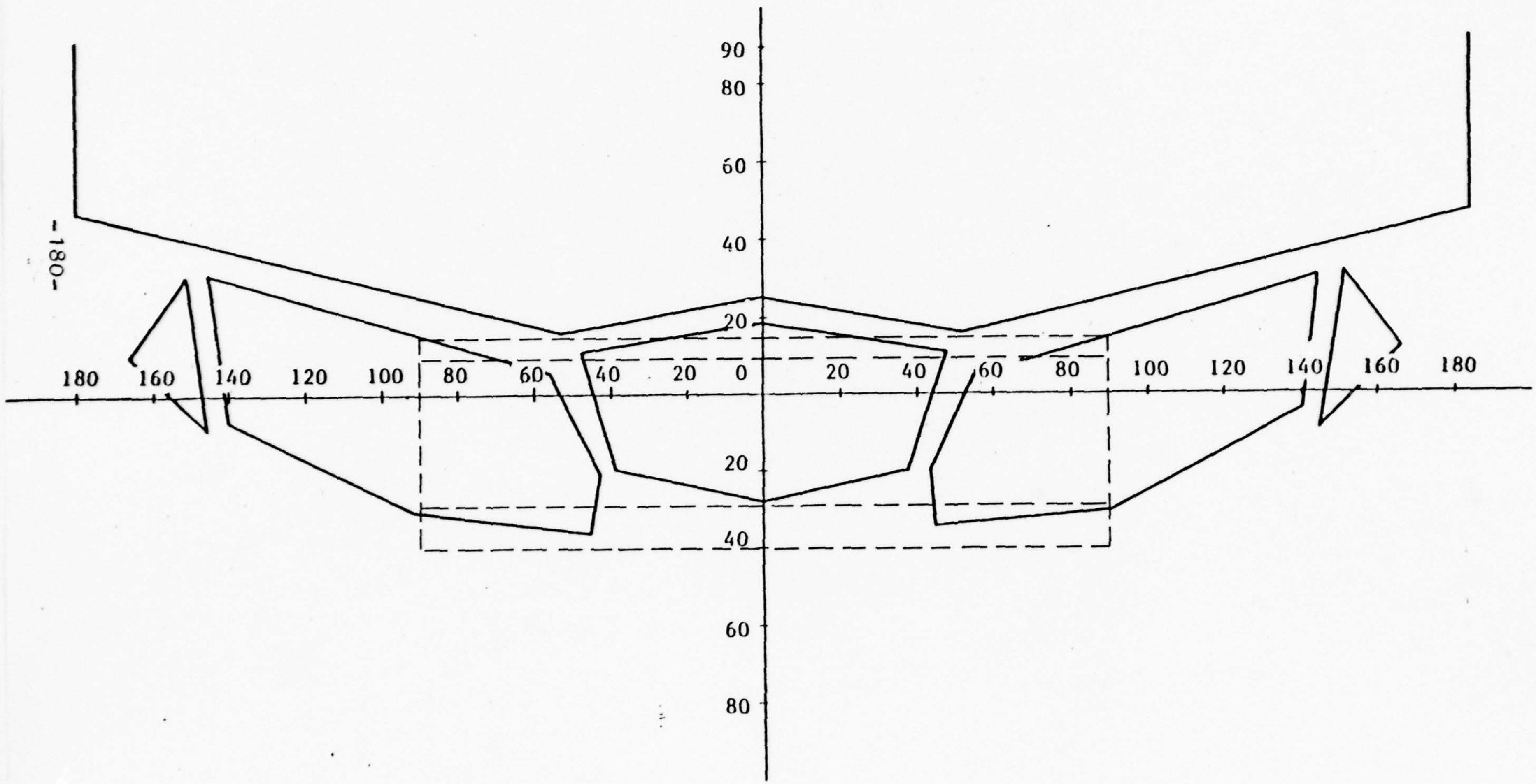


Figure 35. 40°/55° FOV versus CPG Vision Plot

It is germane to look at the resolution of the cinematic display for comparison purposes. The bottom of Table 7 shows, for both 35 and 70-mm film, resolution figures in TVL/PH for comparison with the TV display, and vertical resolution figures for 55° and 40° fields of view in both min/TVL and min/optical line pair. The table shows that 35-mm film resolution is over double the best TV resolution obtainable. While 70-mm film is 4 times better, the improvement is probably unnecessary. Thus, a 35-mm film display is considered adequate and cost-effective for the AAHT.

Capacity to Provide Scene Details

The capacity of a CGI system to create visual details has been measured in the past by the number of edges that can be displayed simultaneously. Most existing CGI systems for aircraft display on the order of 1500-2000 edges. This has been found adequate for most aircraft handling simulation. More recently, marine bridge simulation involving a changing situation with several other moving ships has incorporated a 4000-edge CGI system. 8000-edge systems for high-performance aircraft (the FB-111) are now in construction.

The most recent advances in ability to produce scene details involve the addition of feature generators to the CGI system. These feature generators do not utilize or conflict with the edge generation and manipulation that makes up the basic scene, but enhance the detail by providing added visual features either within edge boundaries or independently. Feature generation is presently being done in laboratory systems, but the state of the art has grown to the point where such capability is being specified for systems being procured in the near future. One type of feature generation can add textures to polygons in the visual scenes. This can be used to simulate a plowed field or random leaf patterns on trees without using up the edge capacity of the system. Another can generate circular objects directly, so that round solids such as silos or fuel tanks can be constructed with very few edges. An

additional aspect of feature generation is to use the point light capacity of the CGI to create or enhance objects by creatively applying dot patterns or clusters. These techniques give the modeller additional tools to generate more detailed and realistic scenes than were possible before. This is required here because a key concept in the AAHT is to display the tactical situation and the conditions of NOE flight in sufficient detail to provide a high degree of transfer of training. Both of these involve modeling terrain, vegetation and threats to a greater extent than has been done in the past.

Detailed modelling can certainly be done, but it must be capable of being utilized. Computer Image Generators are memory-oriented devices; a new picture must be calculated 30 times a second. While operating speeds are increasing somewhat, memory capacities are experiencing phenomenal growth with no end in sight. With the availability of feature generation, we can choose a CGI capacity which represents some growth beyond 8000 edges for a high order of visual capability with confidence. Without feature generation, it is estimated that edge capacity alone might require a very large increase, say an order of magnitude above present 4000 edge systems, to provide the AAHT visual desired. 40,000 edges would provide a highly detailed display, but feeding such a machine might make modelling and data base preparation too painstaking and time-consuming, with diminishing returns for the added increments of details. With the ability to provide features, we can choose a more reasonable system capacity within reasonable reach of today's technology. Such a system, coupled to a data base that is also a reasonable step from today's bases, can provide a significant increase in scene content and detail, and in training effectiveness. Thus a 16,000-edge capacity plus feature generation for the windshield display is chosen as a natural and low risk sizing of a generator based on anticipated 1978-9 technology.

Channel Edge Allocation. It should be clear that the 16,000-edge capacity is applied to the windshield pipeline computer of the CGI. This has a five-channel output to five display projectors. Since the pipeline handles the 180° azimuth display as a single block of data up to the point of collecting it all into a TV frame, the total CGI capacity can be applied across all the channels or across any one or more. Most analyses of CGI scenes assume equal distribution around a 360° azimuth scene. However, in the real world and a real data base representation, this is most rare. In many cases, a concentration of objects of interest is surrounded by little detail. Thus, it is necessary that the generator handle density of detail that varies considerably with both azimuth and elevation. Edge allocation among channels is therefore unrestricted.

Edge Crossings per Raster Line and Total Edge Crossings. Another important measure of CGI capacity to display scene details is the count of edge crossings per raster line. Edge capacity is a measure of the generator's capability to handle the data base objects formed of polygons bounded by edges. After being transformed, windowed, scaled and perspective-projected, this data must be scan-converted to TV format for eventual display by a TV system. The count of edge crossings per raster line and total edge crossings is a measure of how many TV line segments the CGI system can handle after scan conversion. Because TV lines are handled in sequence, one at a time, and then stored in a buffer to form a whole TV frame, both total and per-raster line counts are importnat. The relationship between edges and edge crossings in any system is a statistical one which is primarily dependent on scene patterns and own-aircraft attitudes in relation to those patterns.

Sperry's experience on this subject is based on the development of a marine simulator. In order to add more detail to the CGI scene, the edge crossings per raster line were quadrupled from 250 to 1000. This work showed that 1000 edge crossings per raster line

is adequate for excellent detail. A total edge crossing capacity of about 150,000 appears compatible with this for a 1023-line system.

Data Base Storage Capacity

The data base must be stored on disk for ready access by the visual system computer. The total edge quantity for the planned gaming area is expected to be in the 300 to 500 thousand range. A number of data bases in this size range can be prepared and placed on one or more disks. In this way the instructor can call up the type of data base he wants. A change to a completely different data base is of course, controlled by the central simulation computer because usually other changes must accompany the visual area replacement. However, the change at the CGI system can be accomplished in about 5 minutes. Once the new data base is on line, initialization for starting a new scene is less than 30 seconds.

Gaming Area

The visual gaming area must be large enough to accommodate areas of terrain that may be different in type or may represent different parts of a mission, including stagefields, contour flight zones, NOE flight areas, the FEBA, and the threat area. In addition to being long enough for realistic training, the area must be wide enough to permit a reasonable variety of courses to be laid out so the students are not likely to become too familiar with them for effective training. Considering these factors, together with data base preparation and system edge capacity, an area of 10 x 30 nautical miles is suggested as a good compromise.

Object Image Range

The object image range is related to the processing capacity of the CGI general purpose computer and the desired spatial location resolution. For a 32-bit machine, quite a wide range is possible. Range resolution accuracy can be on the order of 1/40th foot (0.3 inch). Since most flights are terrain type where viewing

distances are from a few feet to a few miles, a compatible object image range would be five feet to seven nautical miles. It should be realized that this allows the whole gaming area of 10 x 30 nautical miles to be utilized for close range operations, because a seven nautical mile band around it will show objects to the student, although he cannot fly closer than the gaming area allows. This permits a realistic condition of the visual scene to continue to the edge of the gaming area, as large objects can be seen seven miles further.

Point Light Capacity

In addition to the simultaneous edge display capacity, the CGI system must have the capacity to display point lights in day, twilight and night conditions. A capacity for 2,000 lights plus 8,000 more from the 16,000 edges could be modelled, if required. Within the 2,000 lights, various colors and flash patterns can be assigned to provide airport lighting simulation. Edges can also be used to create large area lights of any shape or size. Called perspective lights because their aspect changes with view angle, these can be used to simulate lighted windows or any area light. The point light capacity can also be used to enhance the daylight scene by making objects composed of such points, which can be any color or intensity. These can be particularly effective in weapon effects simulation. With these techniques an impressionist effect can be given to selected parts of the scene.

Illumination Levels and Direction

The CGI system can simulate light levels from daylight, through twilight to full night conditions. The limitations are only the maximum brightness output of the display, which must be equated to full daylight; and the scattered light from the display for full black video, which restricts how black the simulated night can be. In addition to ambient illumination, directional illumination as it comes from the sun or moon is simulated. This provides

realistic shading of surfaces in relation to their angular position to the light, although shadows are not simulated. The instructor or the software scenario has control over all these conditions, and realistic sun motion with time can be included.

Moving Objects

Independent moving objects are an important part of the weapons and threat simulation. They are needed to simulate tracers, Hellfire missiles, tanks, armored vehicles, mobile artillery, etc. To do a reasonable simulation of a mission that might entail all of these, about 20 moving coordinate systems are proposed. These can be used for single objects like one missile, or for arrays such as a column of tanks maneuvering together. The motions can be controlled by the scenario software with instructor override, or by an instructor directly.

Update Rates

The input data rate from the central simulation computer is at 30 hertz, to be compatible with the frame rate of the TV display. Now the question arises as to whether this information can produce a satisfactory scene if it is processed at this same rate. The primary determinant is the visual acceptability of the TV scene under normal and extreme conditions. If we examine the scene produced by the aircraft flying at a 100-knot rate in a typical NOE condition, we see that objects close to the aircraft, both below and alongside, will move at relatively high angular rates as they approach the limits of the large field of view, especially at the closer limit of the object image range. If we update the scenes at the TV frame rate of 1/30 sec, the angular distance between successive frames may become so large that the eye will not integrate it into smooth motion, and it will appear jerky. We can avoid this by operating the scene processing at the field rate, which is twice the TV frame rate. This permits an updated position for each interlaced field of the scene, reducing any tendency to lose the

integrating effect of the eye. To process at 60 hz, some additional hardware is necessary, or a reduction in simultaneous display edge capacity is experienced. On the other hand, significant portions of the training time may be spent with aircraft situations that create low angular rates, where 30 hz update of the visual scene is quite adequate. Thus, it is suggested that the capability to operate at field rate update be incorporated, but that sensing of the scene angular rates provide switchover from the normal 30 to 60 hz updates only when the situation requires it. The equipment capacity is defined at 30 hz, with additional hardware to permit field rate operation, with some reduction of scene density. It is anticipated that field rate operation would occur less than 20% of the simulator usage time. During field rate operations, the input data at 30 hz must be interpolated to provide the proper data. In this way, operation at field rates has no impact on the simulation computer.

Quantization Smoothing

The CGI TV display is a quantized picture. The TV lines represent a quantization in the vertical direction, and the resolution elements along a line represent quantization in the horizontal direction. In a CGI-driven display this quantization becomes noticeable because the generator makes an explicit decision on every picture element (pixel). Without quantization smoothing the entire pixel is either the color on one side of an edge or the color on the other side. Most systems now incorporate at least horizontal smoothing, wherein the picture element is split into four or eight parts in the horizontal direction so that in-between colors can be added at edge boundaries. This prevents the appearance of "stair-stepping" or "rastering" associated with the raster structure of the picture, which is seen even in a static picture. Even with horizontal smoothing, dynamic pictures show a vertical quantization as the edge of an object "jumps" from TV line to TV line. This is

particularly noticeable if the edge is nearly parallel to the scan lines and further is exaggerated if it is also short in comparison to the line spacing. Usually, each end of a horizontal edge moves independent of the other edge and the visual effect is a "walking" action of that edge of the object. The latest CGI systems have successfully dealt with both problems. First, new algorithms were developed which tied together the ends of short edges to eliminate the walking effect. Next, pixels were split into 2 or more pieces in the horizontal direction so that the color could be determined on a subscan line basis and then averaged. This subscan line averaging is exactly analogous to the horizontal smoothing. Systems with all these types of quantization smoothing show excellent picture qualities.

Unwanted Visual Effects

Similar in effect but different in cause are other unwanted visual effects that can cause annoying distractions in a visual scene. Such effects as jitter, flashing or scintillation of vertexes or faces, and blinking or disappearance/reappearance of small faces are examples. The better image generators are designed to eliminate nearly all such effects and have successfully done so. A goal of the AAHT CGI is to create and maintain the visual simulation free of illusion-destroying unwanted effects.

Anti-Aliasing Effects on Resolution

All the above quantization and other unwanted effects have been collected under the term "aliasing". The effect of aliasing on resolution is obviously a degradation because of the departure of the scene from the most accurate representation of visual characteristics obtainable. Thus, anti-rastering in a computer generated image is a resolution improvement. Because resolution is usually stated as a single figure which represents limiting resolution of a static TV picture, it is difficult to quantize the aliasing or anti-aliasing effects. However, in thinking of the use of a

CGI scene in a simulator and its purpose, it is clear that reduction of any unreal visual disturbances or enhancement of recognizability of objects - especially small objects - is a practical resolution improvement even if it cannot be put into terms of better limiting resolution or MTF curve area.

<u>CGI Data Base</u>

The data base contains the digital data representing the models and spatial relationships of all visible objects in the gaming area. Preparing the data base involves conversion of map, topographic and model data to compatible digital form for the CGI general purpose computer.

The starting point for terrain data for an actual location (which is probably preferable to a fabricated data base) is the Defense Mapping Agency data. This must be supplemented by photos, topographic maps, special maps for unique areas, and drawings for objects requiring specific details. Cultural features such as bridges and buildings are based on photos or drawings.

Representations of the same areas under IR conditions may be taken from data which sould be available from the Night Vision Laboratories facilities at Ft. Belvoir, Virginia. All this data must be modeled in polygon format representations. Conversion to digital form is done on a digitizer tablet, and conversion programs collate and compile the digitized data into a single origin Mercator projection map in digital data base form for use by the CGI visual system.

Similarly, drawings and photographs of typical target vehicles, friendly aircraft, and weapon effects are modeled and stored to be called up for display by object selection codes in training scenario programs or by the instructor.

Module Integration

The simulation computer uses inputs from the instructor, the cockpit module, and the motion system, together with the initial conditions, to compute the position of own helicopter and all other moving objects which are the primary inputs to the visual module. Table 8 shows the specific inputs to the visual module that are required from the central data processor.

In addition to the positions of the helicopter and moving objects, the simulation computer can control the environment by setting visibility range, which mixes haze into the scene, from unlimited to zero visibility; setting the light level from full daylight to night; controlling sunlight direction; cultural or vehicle lights on/off; and, with variable color coding of the data base, set seasonal features such as snow and vegetation colors. Most of these factors are under direct control of the instructor, who can also select and control moving targets, or he can call up a software scenario to arrange and maneuver a particular threat array. The visual system data base also stores and inserts weapon effects on computer command. Tracer paths or rocket trails are simulated. On helicopter missile release, the flash and smoke are seen, and the tail plume and missile are seen following the path directed by the simulation computer, to the strike on target or miss. The blast effect at impact is also shown, and a hit removes the target object from the scene. The visual weapon effects from other vehicles can also be commanded through the simulation computer by the instructor. Firing flash, tracers, and smoke or dust are included.

The data on crew-selected conditions of the TADS and PNVS

TABLE 8. INPUTS FROM SIMULATION COMPUTER

FUNCTION	INPUTS	
Own Aircraft (Dead Reckoning)	$\bar{X}, \dot{X}$	X position and direction cosines
	$\bar{Y}, \dot{Y}$	Y position and direction cosines
	$\bar{Z}, \dot{Z}$	Z position and direction cosines
	H	Heading
Other Position Orders	$X_c, \dot{X}_c$	X position and direction cosines
	Y_c, Y_c	Y position and direction cosines
	H_c	Heading
	c	Identification of type
	A_c	Altitude (if aircraft)
Environment	Visibility	
	Ambient Light	
	Direction of Illumination	
	Scene Lights	
	Fog Bank	
	Seasonal Effects; Snow, Vegetation Seasonal Changes, etc.	
Own Weapon Effects & Simulation Orders	Tracers	
	Rocket Trail	
	Hellfire Missile Plume	
	Smoke	
	Flash	
	Point of Strike	
Other Weapon Effects Orders	Tracers	
	Firing Flash	
	Smoke/Dust	
TADS/PNVS Data	TADS Turret Pointing Angles	
	Direct View/Day TV/FLIR	
	Magnification Setting	
	PNVS Turret Pointing Angles	
	Designator Active	

must be provided to the visual module by the central computer. The data on the turret pointing angles and selected magnification cause the TADS CGI pipeline to select the proper part of the visual scene stored in the active memory to be processed for visionics display. IR operation for TADS and PNVS is similar and has been previously reviewed.

Operation of the laser designator is simulated and integrated with weapon hit/miss computations and effectiveness evaluation. Figure 36 describes the basic function. A sensor is mounted in the simulated TADS eyepiece display which is activated by the designator control. It acts as a light pen on the video display in that it identifies the TV line and line location designated. The CGI system researches its data base to identify what object occupies that location and can compute its range and direction from the AAH. That data, combined with ballistic/missile hit probability data can be used by the CDP to calculate miss distance of weapons on targets to be used for evaluation of mission effectiveness.

Display System

The recommended windscreen display for the pilot/gunner trainer is a real image projected on a wraparound screen. The real image display offers the economies of common viewing so that both crew members can share the same display system; and contains the realism of parallax effects, including continuity as the viewers look through different windows or move their heads. On the other hand, the real image display system shows only one viewpoint, selected as a compromise between gunner and pilot eye positions, although perhaps it might be worthwhile to weight it toward the pilot's position.

Figures 37 and 38 show a plan view and vertical section of the recommended display geometry. The screen covers 180° in azimuth. Five display projectors are disposed below the

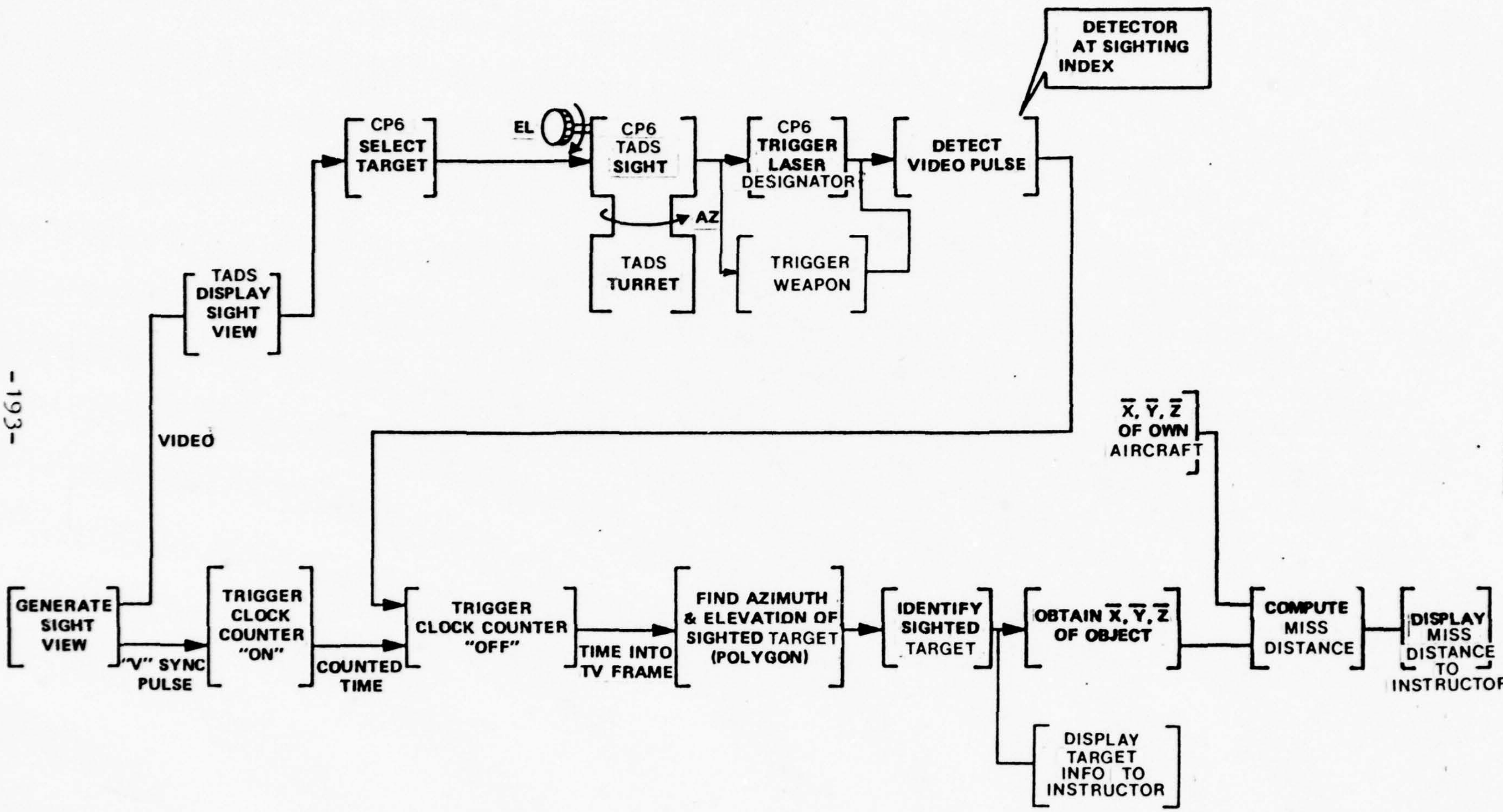


Figure 36. Miss Distance Sensing & Computation Function

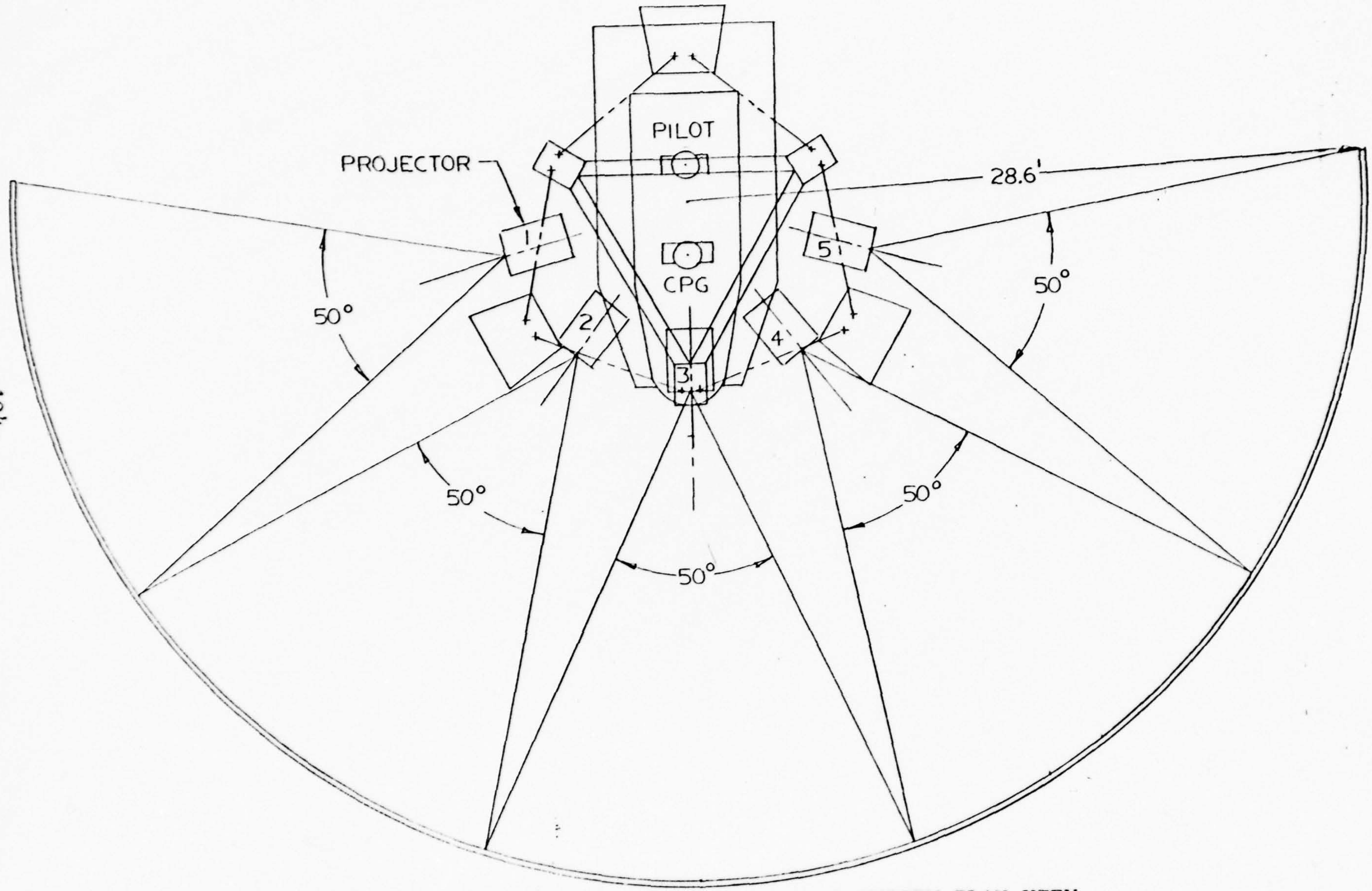


FIGURE 37. PILOT/GUNNER TRAINER DISPLAY SYSTEM PLAN VIEW

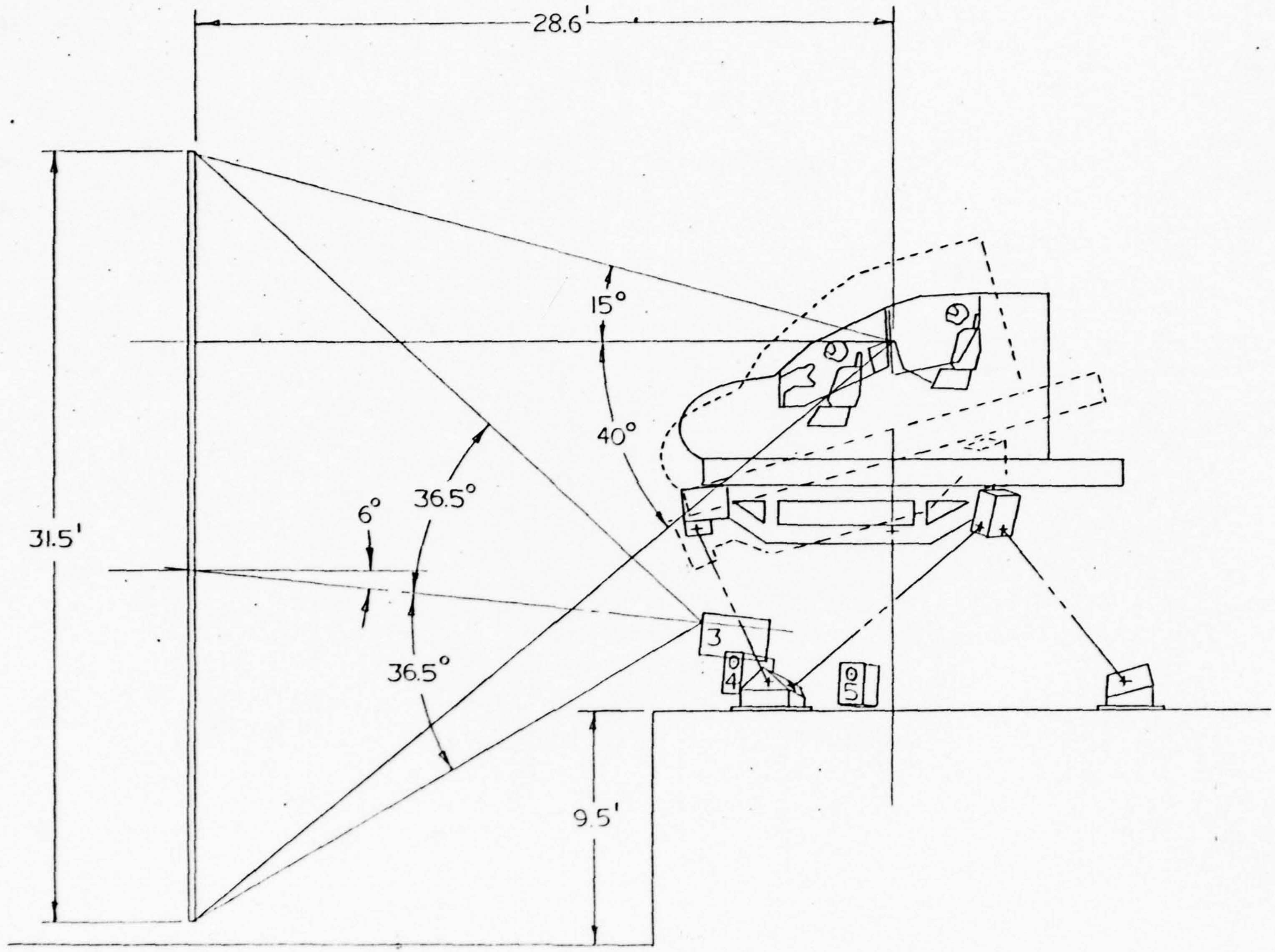


FIGURE 38. PILOT/GUNNER TRAINER DISPLAY SYSTEM VERTICAL SECTION

cockpit module and ahead of the screen origin, and each project a matched 36° azimuth scene for a 180° continuous display. The projectors have anamorphic lenses to convert their standard 3 x 4 format to about a 3 x 2 format, providing an elevation angle of 55° total, arranged to reasonably match the elevation field of view requirements discussed at the beginning of this section. Thus, 15° appears above the horizon and 40° below. This will provide the pilot with enough viewing-angle freedom for terrain flights, including NOE. The azimuth field of 180° is also a good compromise between width of field, number of projectors and display resolution. The origin of the screen is on the line connecting the pilot's and gunner's eyes, equidistant from each. This gives a small parallax error for each crewman varying with bearing angle, as shown in Figure 39. While this error is not correctable in the display, it varies smoothly from 0° for objects directly ahead to about 5.5° for objects directly abeam. Despite the parallax, objects always retain proper relationships, and experience has shown good user acceptance of scenes with substantially greater parallax than those shown here. The pilot and gunner are also separated vertically but the distance from the screen origin is only 0.75 feet. This gives an additional small parallax error for each man of about 2° for objects on the horizon, which decreases to zero for about 20° below the horizon.

Each section of screen is about 566 sq. ft. in area. For a screen gain of about 2, the resulting screen brightness is about 5.3 foot-lamberts for 1,500 lumens from the projector, quite adequate for a simulator visual daylight display. Brightness of the displayed scene varies as the inverse square of the screen radius, and directly with projector output. Brighter scenes could be obtained with a smaller screen radius of say, 15 feet, but parallax errors would grow

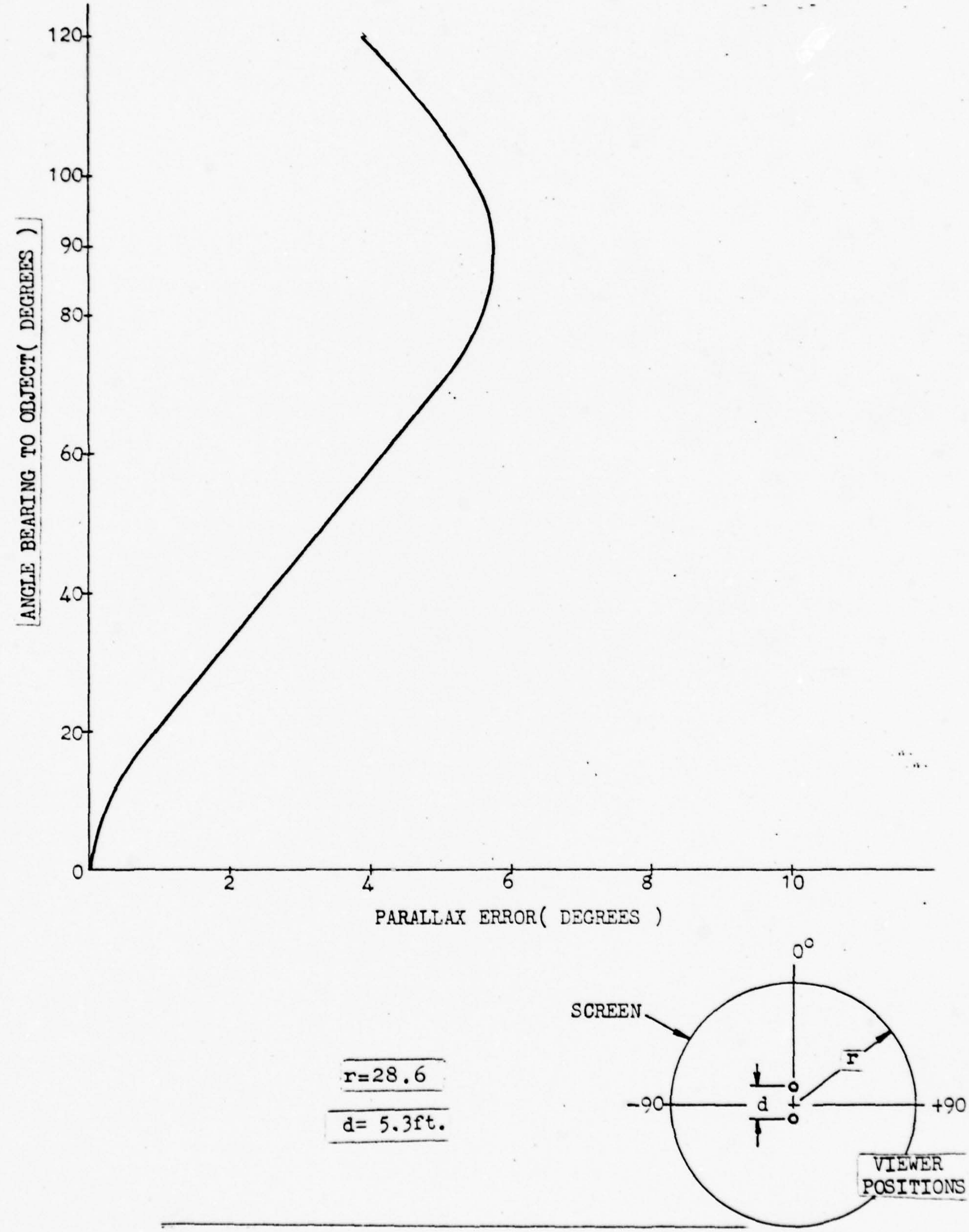


Figure 39. Parallax Error In Crewman's View of 28.6ft. Radius Screen

and the binocular distance cues would increase, which might have a negative psychological effect on the crew in observing rapidly moving objects.

Each projector's scene is matched and abutted to its neighbors to form a continuous 180° azimuth scene. This has already been successfully done by Sperry in a maritime research simulator and the techniques are now well in hand.

The CGI and projectors operate at 1023 TV line standards per RS343. With the image generator providing 600 horizontal picture elements across each TV line, the resolution of the display is about equal in the horizontal and vertical directions, being about 4 arc-minutes limiting resolution.

The LCLV color projectors are expected to be of reasonable size and weight. They are mounted below the cockpit module on a fixed platform. A sketch of the projector is included as Figure 40. The five-projector array must be mounted so that the legs of the motion system and the base of the cockpit module do not interfere with the projection. Minor corrections for line sag and keystoning can be made optically and electronically, giving the operator fine control and distortion-free visuals.

Display Summary

The display system parameters can be summarized as follows:

Display Technology. Simultaneous Color TV. Projectors of the liquid crystal light valve type are used. Five projectors are matched to display a picture 180° in azimuth.

Display Brightness. 1500 lumen projector. Output provides a display brightness of 5 foot-lamberts using a screen with a gain of 2 and a radius of 28.6 feet.

Screen. The screen is a continuous white lenticular surface on vinyl, backed by rigid plastic. The screen configurations and projector output permit a contrast ratio of 25:1 at the points of highlight brightness.

LIQUID CRYSTAL DISPLAY
HDP-2000

HUGHES

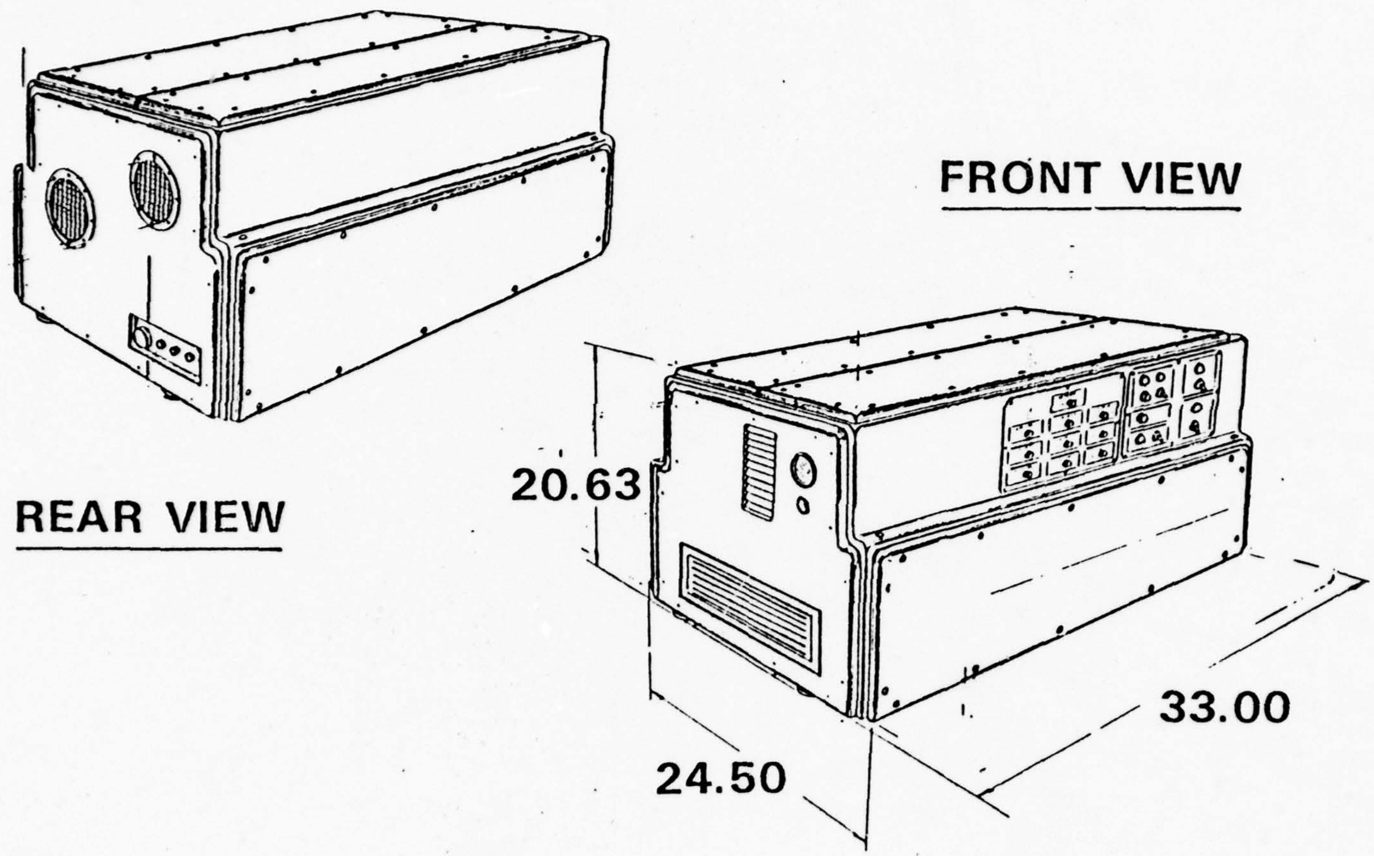


FIGURE 40. LIQUID CRYSTAL DISPLAY HDP-2000

Fidelity. The display distortion is held to 2% or less anywhere in the picture. Stability is ± 2 resolution elements or better.

Parallax. The maximum parallax angle is 5.7° and occurs for objects at ± 90 azimuth.

Resolution. Resolution of the display alone is near 1600 TV lines. Thus, system resolution is not degraded by the display. projectors.

Training Suitability

The principal question at issue, in considering the capabilities of the CGI visual system, is whether that system, with its stylized display, can fulfill the training requirements of an attack helicopter. It can be argued that the real issue is whether a CGI system is better than a model board system; but regardless of the advantages of CGI, which have already been presented, the fact remains that CGI must meet a bottom-line standard of acceptability. If CGI is deemed not acceptable, the alternative is to use a model board regardless of its limitations, unless it also does not meet the minimum standard. If no visual system is determined to be adequate, the consequences will be that the bulk of the visual training load must be borne by the helicopter, as it has been in the past.

The Sperry SECOR study group has thoroughly considered the AH-64 training problem with full understanding of the capabilities and limitations of CGI technology and has concluded that CGI, even with the current state of the art, is better than minimally adequate. Possible improvements in the future will, of course increase its capability to fulfill all training requirements.

Training in the AH-64 can be categorized as either "institutional" or "operational". Institutional training consists of familiarization and initial qualification training given at Fort Rucker, Alabama; and operational training is the more advanced, continuation training conducted at units located worldwide.

CGI is entirely suitable for most of the training tasks included in institutional training. These tasks include aircraft handling, normal and emergency procedures, and weapon indoctrination. Other tasks, such as terrain navigation, which require a visual scene with great detail and accurate resolution, must be accomplished with a cinematic system, as has been discussed previously.

Operational training tasks primarily concern tactical employment of the helicopter and use of weapons against realistic targets, although a certain amount of training in the AH-64 FWS in the field will undoubtedly be devoted to emergency procedures and instrument flight, which, of course, do not need a visual system at all. It is in the area of operational training that CGI suitability is most often questioned.

The questions usually focus on whether the student can observe the stylized depictions of natural and cultural features that are characteristic of CGI displays and then make the decisions and take the actions that would be appropriate to a real-world situation. Likewise, there is a question regarding whether the student will absorb lessons learned in this way, and later apply them to problems occurring in actual flight in the helicopter, e.g., the classical question of transfer of training.

To a large extent the response to these questions depends on the nature of what the student is trying to learn, i.e., his training objectives. These objectives, in broad terms, can be identified by referring to the individual and crew standards listed in sections 2-2 and 2-3 of TC 17-17.

One of the individual standards states that attack helicopter pilots and copilot/gunners must be able to use terrain and vegetation for cover and concealment while in terrain flight modes. It is considered that this task can be easily accomplished with CGI,

even through the terrain is depicted with smooth contours and the vegetation does not show individual leaves and branches. The student can readily recognize the terrain and vegetation features that he should use for concealment, and can fly the simulator appropriately. Errors made by the student, such as crossing an open field, failing to navigate down a nearby draw, or not keeping close enough to a line of trees, can be easily observed by the instructor and brought to the student's attention. The fact that the features on the display are stylized rather than realistic will not diminish the ability of either the student or the instructor to perceive what is being represented and what is taking place.

Another standard states that crewmen must be able to receive target hand-offs and move swiftly from a holding position to an attack position. In this example, the holding position can be behind a ridge or a grove of trees and the attack position can be forward to a point where the target can be acquired. Although the resolution capability of the visual system becomes a factor in the process of target acquisition (also true for model board technology), the stylized display of CGI-drawn ridges and trees will not prevent the student from learning the characteristics of a holding position or an attack position and being able to use them properly, whether in a simulator or a helicopter.

Other, more complex standards state that crewmen must be able to engage certain types of targets with designated weapons, using techniques of engagement appropriate to the target and range; to transition from one target to another, using all weapons, all terrain flight modes, and all techniques of engagement appropriate to varying situations; and to select and apply the proper flight mode and techniques of engagement for a particular type target and set of conditions.

These standards are very demanding on the visual system; in fact, they constitute the crux of the operational training problem.

However, the features of the visual scene that are involved in the training process in these examples are the same as in previous examples--targets, such as tanks and other vehicles; nearby elevations or vegetation behind which the attack helicopter can be concealed; and distant elevations or vegetation behind which targets can be concealed and from which they can emerge and be engaged. As discussed previously, the CGI representation of these features will be recognizable to the student, and it is considered that he will be able to select a terrain flight mode, choose a weapon and engagement technique, and engage the target or targets as conscientiously and properly as if he were in the helicopter itself.

The resolution capability of the visual system--of any non-cinematic visual system--may inhibit the student's ability to detect, identify, and engage targets at the maximum ranges desired; but this is a separate limitation, not related to the stylized displays of CGI. While it is desirable to be able to depict targets at 3700 meters range, a maximum acquisition range of 2000 meters, for example, would not vitiate accomplishment of the fundamental training objectives. Also, the CPG will be using a variety of visionic equipments with different magnifications, and unaided visual acquisition will not figure significantly in weapon employment, except for initial target detection.

An even higher order of tasks would include evaluation and engagement of targets of opportunity, response to hostile fire, and perhaps reaction to an enemy airborne threat such as an enemy helicopter. In all of these, the amount of detail in the visual scene is unrelated to the student's ability to assess the situation and take the proper action.

The salient principle common to all aspects of operational training is that the tasks are primarily judgmental or procedural. What is being developed, and later evaluated, is the student's knowledge of weapon employment and helicopter tactics and his

ability to determine and apply the correct action or procedure called for by a particular situation. Also being exercised is crew coordination, between the pilot and the copilot/gunner.

Generally, the correct action, or actions involving both crewmen, must be taken very positively and quickly. If, for example, the attack helicopter is engaging a target and comes under fire from a different threat, a situation results which requires prompt evaluation and reaction. Many factors, such as the type of target being engaged, the source of the hostile fire and its intensity and accuracy, the availability of assistance, etc., will go into determining the correct action. Situations such as this can be reproduced with CGI and valuable training accomplished, and such training will be minimally impacted by the fact that the visual scene is depicted with a stylized display.

Integration of Visual and Motion Systems

Ideally, for a "one-to-one" transfer of simulator training to real world flying experience, all controls, displays and human sensory cue generators should be matched to real world occurrences. This matching is a major problem in all simulators. The response of aircraft instruments and aural devices to controls such as throttle, stick, etc. can be simulated very accurately with very small delays or lags which, at a 30-Hz iteration rate, average 25-50 ms. Visual scene displays, however, cannot be manufactured without significant delays. For a CGI system, the processing or throughput delay is in the order of 3 to 4 TV frame times, i.e. 100 to 133 ms. For reproducing acceleration cues, the motion system lags are approximately 150 ms and up (depending on the size of the system) because of the inertia of the electro-mechanical-hydraulic servo system. Thus, it can be seen that all devices creating the visual, motion, instrument, aural and aircraft control environment in a simulator may have different delays and therefore create problems in transfer of simulator training to real world training.

These problems have been studied by behavioral scientists and engineers for many years. Experiments have been conducted where all simulation devices were appropriately delayed, except for aircraft controls, so that all devices had the same delay as the slowest simulation device (the motion system). The results verified the intuitively obvious expectations, that the simulator lost its effectiveness as a training device. This is analogous to introducing delays and lags into servo systems, degrading their stability. When the pilot trainee moves his control stick, he expects certain aircraft reactions, particularly in the visual scene and on the instruments. When the simulator responses are delayed to match the slowest simulator device, the pilot does not get the expected response. He then moves the control stick even more than on the real aircraft to get the expected motion. The result is poor flight stability since he is over-controlling the simulated aircraft. Soon the trainee learns that he must anticipate aircraft reactions to get acceptable aircraft flight. The net result is that the trainee begins to regard the simulator as a game rather than a useful training tool.

Because visual delay effects are more noticeable than instrument effects (since the visual display provides a far more precise indication of roll response and dynamics than is available from attitude instruments), some compensation must be provided for the visual system delay. A second order Adams numerical integration method is preferable over a straight Taylor Series extrapolation technique since the former is a time compensation technique whereas the latter is a position compensation technique. Visual compensation should be equal to the difference in delay between the visual and instrument system, thereby having the visual system track one-to-one with the instrument system.

Experiments (Gum and Albery, 1976) without visual system compensation have shown that the preferred arrangement is with

the visual lag reduced as much as possible regardless of the disparity between the motion and visual cues. G-seat delays which were on the same order as the motion system were not disturbing. This was to be expected since the G-seat was not intended to provide rapid on-set cues, but rather sustained acceleration cues.

Compensation cannot be incorporated into the motion system to reduce motion cue delays since the function of the motion system is to generate onset acceleration cues only. Onset acceleration cues occur almost immediately after the pilot moves his controls, except for lag in the aircraft surface servos or propulsion plant. Compensation of the motion system to anticipate the aerodynamic surface servo and propulsion time constants would be generally insignificant compared to the motion system hardware time constant.

Other simulator experiments have shown that the best performance can be achieved when the visual scene is generated as fast as possible (i.e., with minimum throughput delays), reproducing the expected scene motion in immediate response to the movement of the aircraft controls by the pilot. This is logical since behavioral scientists have shown that in visual flight conditions the pilot uses cues in approximately the following ratios: 80-85% visual and instruments, 10-15% aural, and 5% acceleration cues. This high dependence on visual and low use of acceleration is validated by aircraft simulator experiments which showed that pilot training performance on simulators was not significantly affected with the motion system on or off. In some cases, the pilots had regarded the motion system cues as "noise" because it severely lagged the expected real world cues. Therefore, these pilots had to make an extra effort to filter out this noise from other information in order to make piloting judgments. In such cases the pilots performed better with the motion system off.

When visual scene information becomes obscured because of fog, cloud formation, etc. (or if the visual system contains a very low level of detail), the pilot no longer has adequate visual information to make reliable judgments. Under these conditions, the pilot primarily depends on instrument, aural and motion system cues. Thus, training experiments under IFR conditions (or where poor visual systems were used) show that the pilot performs better with the motion system on, even though it is significantly delayed beyond the real world responses. Without adequate visual and no motion system, pilots were noted to have greater tendencies to vertigo (Stark, 1976).

From all of the above, it can be concluded that is is most important to have the instrument and visual system response track the aircraft response faithfully with respect to aircraft control inputs since 80% of pilot information is derived from these systems. Ideally, it would be desirable to have the motion system acceleration cues also faithfully track aircraft response to control stick inputs. Since motion systems are large electromechanical-hydraulic systems, this goal cannot be fully achieved, and despite the use of predictive techniques, acceleration cues must be expected to lag behind the visual system. Human perception of acceleration cues is not as well developed as the visual and aural senses. Therefore, the concept of "do-the-best-you can with the visual-aural-motion system but do not deteriorate any subsystem performance to match the motion system lags" is a viable approach to developing simulator trainers.

A major reduction in motion system lag has been achieved by NASA with the "inverse transform" technique. Response times of 30 ms have been obtained, which if applicable to commercially-produced 6-post synergistic motion systems, would effectively reduce the integration problem to one involving only visual systems and instrument displays.

The majority of flight simulators that include visual systems together with motion platforms have used virtual image display. Because of the limited viewing volume, these displays have been mounted on the motion platform so that the crewmen and the display system were fixed together. Integration of the motion/visual system thus involved only the differences in their dynamic responses when driven by the same data from the central simulation computer. As we have discussed, response times of motion systems are currently on the order of 150 milliseconds or somewhat more, while for daylight CGI visual generators, the response is 100-132 milliseconds. Since the response time of motion system lags that of the visual system, and both lag the actual aircraft, some attempt to match these must be made. It has been common practice to employ extrapolation algorithms to variables used for visual scene generation. These algorithms basically predict aircraft attitude and position based on current values and rates. Similar algorithms can be used to partially predict motion position. To do this properly, a rigorous analysis of the motion system transfer functions is required. Because one major motion input, pilot stick movement, cannot be predicted, full correction of motion lags is not anticipated, but sufficient compensation to eliminate inappropriate motion cues is achievable.

In the proposed AAHT mission trainer configuration, the display is not mounted on the motion platform. Instead, a real image display using fixed projectors and a fixed screen is used. With this uncoupling of the motion and visual display systems, an additional series of compensations is required to insure that the visual scene remains in correct perspective to the crew's frame of reference, i.e., the cockpit, and flight instruments. To accomplish this, pseudo pitch, roll and yaw angles must be

calculated based on both aircraft simulated attitude and actual motion system attitude. For example, pitch must be computed as follows:

$$\Theta_{PROJ} = (\Theta_{AC} - \Theta_{MOT})$$

where:

Θ_{PROJ} = projected pitch angle

Θ_{AC} = calculated aircraft pitch

Θ_{MOT} = calculated motion pitch

For an instantaneous condition of $\Theta_{AC} = 5°$ nose up and $\Theta_{MOT} = 3°$ nose up, the calculated visual scene would be displayed for 2° nose up so that the horizon with respect to the cockpit structure would appear to be 5° below the straight and level position. Roll and yaw corrections must be implemented in a similar fashion.

Lateral, longitudinal and vertical translations must also be accounted for. These displacements can be accounted for by a variable eyepoint calculation. For instance, if the motion system moves one foot to the left, the calculated eyepoint would also move one foot to the left, thus keeping the visual scene position constant with respect to the trainee.

Note that these corrections will take care of the fact that the motion system is used for acceleration onset cues only; subsequently, a washout phase returns the cockpit to level, natural position. With the simulated attitude and actual attitude driving the visual generator, the display will always retain its proper aspect for the crewmen. Thus, integration of the motion and visual systems with the cockpit and crew is seen as combining a series of known techniques of low to medium risk, with the only risk area the generation of proper extrapolation algorithms.

COMPUTER SYSTEM MODULE

This portion of the study report addresses the items listed in the Computer Section Study Outline contained in Attachment 4 to the contract. The order of investigation was somewhat different from that contained in Attachment 4, as explained in the following.

Computer System Evaluation Process

The computer system evaluation process was composed of five phases. The first phase was a data-gathering phase, applicable to all four of the remaining phases. Data gathering included compilation of published data, informal interviews with simulator users, interviews with cognizant Sperry SECOR personnel and interviews with computer vendor personnel.

The second phase was the evaluation of certain design considerations in the areas of:

1. Use of FORTRAN IV (as opposed to assembly language).
2. Use of computer manufacturer's operating system as a real-time executive.
3. Use of real-time on-line diagnostics.
4. Use of MOS memory (as opposed to core).

These considerations were evaluated, and conclusions reached in order to proceed with phase three, establishment of the computer system criteria. Computer system criteria were divided into two types, pass/fail criteria and quantitative/qualitative criteria.

The fourth phase was to investigate the available computer systems to determine if they met or exceeded the criteria established in phase four. Any computer system which did not meet the pass/fail criteria was immediately eliminated from consideration. The computer systems were then measured against the established quantitative/qualitative criteria. In addition to the qualitative-quantitative criteria, such factors as cost and I/O structure were also analyzed for each of the candidate computer systems.

The fifth and final phase was to select the best computer system for the AAHT on the basis of the investigation conducted in phase four. Once the computer system was selected it was then possible to configure the computational system that would meet AAHT requirements.

The computer systems portion of this study is organized in four parts corresponding to phases two through five.

Use of FORTRAN

Studies have shown that the number of lines of debugged code a programmer can produce per month on a project over a period of several years is approximately 100 to 200 lines, independent of the programming language used (Corbato, 1969). Only on small programs is higher productivity achieved. Therefore, if one FORTRAN statement is equivalent to 5 to 10 assembly language statements, the productivity of a FORTRAN programmer would be 5 to 10 times that of an assembly language programmer.

Another argument against programming in assembly language is that assembly language coding, although vastly superior to pure machine language coding, is more time-consuming and difficult, and requires knowledge of the computer architecture. Effort by the programmer is required to learn the particular computer's assembly instructions. Since all problems must be broken into simple steps, much repetition and, with it, extra effort must be exerted by the programmer. Because of the resultant complexity of a particular programming task, there is a direct impact on the number of errors introduced and, thus, on the length of the debugging cycle. All of this is also true of maintaining assembly language code.

What is more, understanding someone else's assembly language program is very difficult. Furthermore, turnover of government software maintenance personnel is typically high. New programmers must spend a great amount of time learning the software before they can effectively maintain it. Often, their assignment ends shortly after or even before they can effectively maintain the software.

Many of the above-mentioned problems of assembly language programming are circumvented using a high-level language. The programming task is thereby simplified to the point where the programmer can perform his task nearly independently of the peculiarities of the computer being used. This is very desirable in the case of simulation modules, which are primarily composed of arithmetic and logic operations. Thus, FORTRAN, which was developed primarily for algebraic computations, is ideal for the aerodynamics and engines simulation modules. Since most FORTRAN's now include boolean logical operations, FORTRAN is also ideal for the remaining simulation modules.

However, real-time executive tasks such as I/O handlers and memory management, to name a few, are highly dependent upon the particular computer's architecture. Because assembly language is closely related to machine architecture, the programmer can take advantage of various hardware features that are unique to a particular computer. In addition, where the economics of the system dictate the use of a minimum amount of primary storage, the programmer is forced to economize in the number of instructions in his program. Assembly language allows the greatest such optimization of program size. Since large program size generally means longer execution times, program size becomes important to trainer performance in time-critical applications such as the real-time simulation executive; therefore, the executive should be written in assembly language.

Studies have shown that, in most programs, a small percentage of the total code is responsible for a large percentage of the execution time (Dardner and Heller, 1970). It is common to have 10 percent of the code using 90 percent of the execution time.

Assume, for example, that it requires 10 man-years to write some large program in FORTRAN and that the resulting program requires 100 sec to execute. Writing the whole program in assembly language would require about 50 to 100 man-years, due to the lower productivity of assembly language programmers; the final program, however, would execute in about 33 sec, since a clever programmer can outdo a clever compiler by a factor of 3 (Tannenbaum, 1976). This is because the code generated by a compiler uses a subset, typically fewer than 20 percent, of the total number of available assembly language instructions (Tannenbaum, 1976). The instructions used are those of a general nature, and the subset can perform any required function. However, the remaining instructions are less general: they frequently combine two or more of the functions of the general instructions. The clever programmer, therefore, by using the more specific, multifunction instructions, can produce much more efficient code than a compiler does. Once again, this is very important to the real-time executive, which should therefore be written in assembly language.

Another approach (other than all assembly code or all high-level code) to producing software is called tuning. Tuning is based on the empirical observation (documented by Dardner and Heller, 1970) that, for most software programs, a small percentage of the total program is responsible for a disproportionate amount of execution time. All software is first written in a higher level language. Then, it is determined which

parts account for most of the execution time. For example, assume that 10 percent of the total program accounts for 90 percent of the execution time. This means that for a 100-sec job, 90 sec are spent executing the critical 10 percent of code and 10 sec are spent executing the remaining 90 percent. The critical 10 percent is now improved by rewriting it in assembly language. Additional time is needed for tuning of the critical code, but its execution time is reduced, thus boosting its performance.

In the case of real-time aircraft simulation, we already know which portions of the code are responsible for disproportionate amounts of processing time. Typically, when all the programming is done in assembly language, the real-time executive and trainer I/O, which comprise only 2 percent of the total code, require about 10 to 15 percent of the actual processing time (not including spare time). Therefore, if these portions of code (real-time executive and trainer I/O) are written in assembly language in advance, the expense of the tuning process is avoided but the performance advantages are retained.

The FORTRAN (FORmula TRANslation) language was designed for mathematic processes, as its name implies. Therefore, by reason of the language's design, FORTRAN has several characteristics which would limit the capabilities of some processing tasks. These characteristics are as follows:

1. Inflexibility of input format.
2. Lack of reentrancy.
3. Lack of efficient text handling capability.

Each of these characteristics and their impact on certain processing tasks is described below.

Because FORTRAN input formats are inflexible, the performance of the graphic page compiler and the off-line test programs would be degraded if FORTRAN teletype and card reader input handlers are coded in FORTRAN. These two programs must use either the teletype or card reader input handler to process each and every source statement that comprises the graphic page being compiled on the simulation module being tested. Most FORTRAN I/O is fixed-format; and, a greater possibility of I/O errors exists with fixed-format I/O than it does with free-format I/O. More important, unless the FORTRAN ERR function is implemented, an I/O error will cause program abortion. This is disastrous in terms of efficiency, since the programmer must recompile his graphic page or retest his module each time a single error is encountered. Clearly, it is more desirable to discover all presently existing errors with a single execution of the graphic page compiler or the off-line test program.

The effectiveness of both the graphic page compiler and the off-line test program as development tools depends greatly upon the amount and specificity of error information that is provided to the programmer. With the ERR function, when an I/O statement error is detected, execution is not halted. Instead, execution is transferred to the instruction indicated in the ERR field of the I/O statement. An error message may then be printed and the error corrected or overlooked so that execution may continue with the next source statement of the graphic page being compiled or the module being tested. However, not all FORTRAN compilers implement the ERR function. Even with the ERR function, there is still the problem of supplying an adequate error message. When an input error occurs during the execution of a READ statement, for example, not only is it impossible to determine in which

field of the data card the error exists; it may even be impossible, under some circumstances, to isolate the particular card being read when the error occurred. This severely limits the amount of helpful information that may be provided in the error message. Thus, a certain amount of expertise in successfully interpreting errors would be required by the applications programmer.

With assembly language, on the other hand, input format is much freer, data of any type may be entered in any order separated only by commas, and the chance of input errors is therefore minimized. Furthermore, if the card reader and teletype input handlers are written in assembly language, it is much easier to determine the nature of the error, and therefore, a much more specific error message may be provided.

Fortran is not re-entrant. I/O handlers, however, are separate tasks which must be serially re-entrant unless a number of subroutines utilized by several handlers are incorporated as in-line code in each of the handlers. This results in very inefficient primary memory usage. Furthermore, because FORTRAN I/O handlers add a significant increase in overhead as compared to assembly language I/O handlers, the real-time performance of the simulator as a whole could be degraded if FORTRAN I/O handlers are used. I/O handlers - particularly disc I/O handlers - are highly executed, high priority items which are time-critical during real-time simulator operation. Thus, if I/O handlers, which are slow in assembly language, are written in FORTRAN, which is even slower, this could easily result in a slower response time for the module-related simulator cockpit instrumentation than for the aircraft instrumentation itself. Thus, the training value of the simulator is diminished.

FORTRAN's lack of efficient text handling capability would pose problems for the alphanumerics portions of the graphics programs. The alphanumeric displays would execute much faster if written in assembly language. Because non-byte-oriented FORTRAN is not designed for text processing, data must be either integer, real, complex or double precision; therefore, string and list processing routines written in FORTRAN would require extensive and complicated FORTRAN code, introducing much greater overhead, or would require storing one byte per word, resulting in poor memory utilization. It would be somewhat easier to process text with FORTRAN on a byte-addressable machine. However, to overcome the problems of how to move, split and concatenate character strings would still require extensive or complicated FORTRAN code.

Conclusions/Recommendations. For real-time training simulators, real-time on-line processing involves two basic types of software: executive support software and the actual simulation software. The results of our training simulator survey show that the executive software (which includes I/O handlers and service modules) are very rarely, if ever, changed. Therefore, the development/acquisition cost of this software constitutes the bulk of its life-cycle cost.

The development/acquisition cost of the executive and its related processing tasks is directly related to the developer's prior experience with the chosen language. To date, not a single helicopter trainer real-time executive has been written in FORTRAN; all have been written in assembly language. Due to a number of previously mentioned, capability-limiting characteristics of FORTRAN, a great deal of thought, time and money needs to be invested to pioneer ways of accomplishing certain executive tasks. As

a result, the development/acquisition cost of the executive software would surely be greater if coded in FORTRAN; and therefore, since development/acquisition costs are the greatest portion of the executive software life cycle costs, life cycle costs would also be increased with a FORTRAN real-time executive. However, for previously stated reasons, the use of assembly language would increase capabilities and improve performance of executive tasks without increasing life cycle costs. Therefore, it is recommended that the real-time executive and its related processing tasks be coded in assembly language.

Simulation software, on the other hand, is changed most often as a result of changes to the related aircraft system or improved aerodynamics data for the aircraft being simulated; therefore, in the case of simulation software, maintenance costs constitute a much larger part of the life cycle costs. Since development and maintenance of FORTRAN simulation modules is easier, quicker and requires lower level personnel, and because coding the simulation modules in FORTRAN would not adversely affect simulation software performance, it is therefore recommended that the simulation software be coded in FORTRAN.

Finally, for the performance-related reasons previously stated, it is recommended that the graphic page compiler (preprocessor) and the off-line test program be written in assembly language.

<u>Use of Vendor's Operating System As Real-Time Executive</u>

Several factors must be considered before recommending the vendor-supplied operating system be used as the real-time simulation executive. They are: cost, memory utilization, and feasibility. Each of these factors is addressed separately in subsequent paragraphs.

Cost. The results of our informal user's survey indicate that the real-time executive is rarely, if ever, modified after product delivery. Therefore, the great bulk of the life-cycle support costs is the development cost, in the case of a contractor-developed real-time executive, or the acquisition cost, in the case of a vendor-supplied Operating System (OS). How great an acquisition/development cost saving, if any, is realized through use of the vendor-supplied OS as the real-time executive depends largely upon the contractor's experience with the chosen computer system.

The development cost of a real-time executive can also be nil or negligible if the contractor has already developed a proven real-time executive for a previous simulator on the same computer system that is chosen for the AAHT. For example, the real-time executive developed for the A-4M trainer has not been changed to date. The real-time executive for the A4-International used the A-4M executive as a baseline and expanded its capabilities. The A-4KU uses the exact same real-time executive that was developed for the A4 International. The B-52 G and H Operational Flight Trainers (OFT's) also used the A4 International executive as a baseline and incorporated multi-task programming and other enhancements. Any further B-52 OFT's will use the same real-time executive, with the only foreseeable enhancement being the possible modification of existing I/O handlers to accommodate different peripherals. This type of executive reutilization is possible only because the same computer system was used on all of the trainers mentioned. However, if the contractor has had no previous experience with the proposed computer system, five to six man-years of effort may be required to develop a real-time executive.

The vendor-supplied operating system is purchased whether or not it is used as a real-time executive; it is needed for off-line development of simulation modules. In

theory then, the development/acquisition cost is zero when the vendor-supplied operating system is used as the real-time executive. In practice, however, the vendor-supplied operating system requires simulation-tailored extensions to reduce the resulting increase in overhead which can, if the increase is large, degrade total simulator performance. The development costs for these extensions would again depend on the contractor's familiarity with the computer system, and thus, its operating system software. If the contractor is familiar with the operating system, extending it may be little or no more costly than enhancing the contractor's own real-time executive. On the other hand, if the contractor is totally unfamiliar with the proposed computer system, development of vendor-supplied operating system extensions would be much less costly than developing a real-time executive.

Memory Utilization. The manufacturer's operating system requires more memory than does a contractor-developed real-time executive. This is because the manufacturer produces a general purpose operating system that will satisfy the requirements of all its users. As a result, there are features which are unnecessary for flight trainer applications, but which nevertheless introduce increased overhead and require greater storage space. These effects are increased with multicomputer configurations. Instead of duplicating the manufacturer's operating system in each of the computers of a multicomputer configuration, a more efficient system would be to make one CPU, with the vendor-supplied operating system, the MASTER CPU, with contractor developed special purpose executives resident in each of the remaining (SLAVE) computers. This would decrease the total system storage required for operating system/executive software, while at the same time eliminating the SLAVE processor overhead that would be introduced if the SLAVE computers used the vendor-supplied OS.

Feasibility. In order to adequately support a flight trainer, an operating system must meet a number of simulation-specific requirements. These requirements are listed under Software Requirements in the Computer Evaluation Criteria discussion.

Conclusion. Since it represents the most cost effective approach, Sperry SECOR recommends that the computer vendor's real-time operating system be used as the AAHT real-time executive if, and only if, the operating system meets all the requirements listed in the Computer Evaluation Criteria discussion of software requirements.

Cost Effectiveness of On-Line versus Off-Line Diagnostics.

Those types of memory diagnostics (for either primary or on-line secondary storage) that continually write various data patterns to, and read them from, memory, obliterating its former contents and thereby precluding real-time simulator operation, must always be run off-line. However, certain types of limited diagnostics may be run on primary memory. Address decode lines and data paths may be checked by isolating periods of time in which a single word in each 8K memory module is written and read back. This single word in each 8K module must be test-dedicated: it must not contain data to be used for any other purpose. A second type of limited memory diagnostic would be to perform a limited memory integrity check by simply reading each word from memory and checking its parity. However, this sort of software parity check is useful and cost effective only if parity checking is not offered by the computer vendor.

On-line diagnostics for the mainframe or mainframe option boards are of limited value since a mainframe fault will in all likelihood preclude simulator operation.

The most practical and effective use of on-line fault diagnosis is made in the case of off-line peripherals such as a card reader, line printer or magnetic tape unit. Computer maintenance personnel typically "shut down" the software currently being executed in order to run their off-line diagnostics. In the case of a flight trainer, this means the trainer must sit idle while diagnostics are being run. If the fault occurred in one of the peripherals used only for off-line development, such as a card reader or line printer, on-line diagnostics would allow simulator support and diagnostic execution concurrently, as long as the computer was not overloaded. (With a 100% spare processing time requirement, a computer overload due to on-line diagnostic execution is virtually impossible).

Often, once the problem is believed to be remedied, computer maintenance personnel may let a diagnostic run for hours at a time to assure that the fault is "permanently" fixed, and is not a short-term periodically recurring one. These hours could also be used for concurrent simulator support and diagnostic execution if on-line diagnostics are used.

Even if on-line diagnostics exist, however, the extent of their use and therefore, their cost effectiveness, depends very much on the particular maintenance policy in effect. If an organic computer maintenance capability is planned, then use of on-line diagnostics to save trainer down-time may be enforced. Or, if the computer site is a time and materials customer, the vendor's field engineer may be persuaded to bear with on-line diagnostics so that the trainer may be supported concurrently. However, if contract service is obtained from the computer vendor, then the vendor's field service personnel may very likely "shut down" the software currently being executed and run their off-line diagnostics in order to get off the customer site as soon as possible.

Regardless of the possible benefits to be achieved by the use of on-line diagnostics, Sperry SECOR recommends that they be required only if they are available from the computer vendor. The contractor could provide on-line diagnostics only at a very great expense. The computer vendor, on the other hand, already has a thorough knowledge of the hardware involved. The vendor's effort to produce on-line diagnostics is limited to adapting their own off-line diagnostics for on-line use. And, they have a much wider market over which to distribute the cost of such development. For these three reasons, the vendor can produce much less expensive on-line diagnostics than could the contractor. For example, SEL provides on-line diagnostics for its mainframe, floating-point firmware and mag tape transport for the combined price of $125 for binary cards or $175 for source mag tape. They charge only $10 for a technical description manual which describes all three on-line diagnostics. No contractor could begin to meet these prices.

Therefore, Sperry SECOR recommends that any available on-line diagnostics be purchased from the computer vendor and used as extensively as possible with the purpose of determining which, if any, benefits accrue therefrom.

Use of MOS Memory vs Core Memory

None of the candidate computers provide metal-oxide-semiconductor (MOS) memory. However, since MOS memory is being offered in a greater and greater number of computer systems, it may be beneficial to future trainers to discuss the various advantages and disadvantages of core and MOS memories.

Reliability. The greater reliability of core memory, along with other factors such as proven design and availability of core, are the reason why core memories are still preferred, and why MOS memories were not used sooner in mini-computers of the 24- and 32-bit variety. Unfortunately,

because of the multiplicity of MOS RAM cell designs and the frequency with which new cell designs evolve, it is impractical to quote a numerical mean-time-between-failure (MTBF) value for the reliability of a specific MOS technology, (n-MOS, p-MOS or C/MOS). Because of the great variety of cell designs, there are exceptions to almost every characteristic of a specific MOS technology. Therefore, one must be very careful to limit comparisons to specific memory cells, and to quote MTBF values of specific memories.

A principal factor that definitely affects MOS reliability is junction temperature, which is directly related to power dissipation. The lower the power dissipation, the lower the junction temperature and, as a result, the greater the reliability that may be achieved.

There is also an economic deterrent in the establishment of MOS reliabilities. In the case of bipolar semiconductor products, millions of test hours of reliability data were sponsored by the military. Since MOS circuits have to date been used primarily in consumer and industrial applications, large sums of military money have not been made available for generation of MOS reliability data.

Despite the impediments imposed by economics and diversity of design, MOS reliabilities have improved steadily. In 1972 MOS circuitry had reached the same reliability levels achieved by bipolar circuitry only five years previously. At present, Varian Data Machines gives an MTBF of 38,600 hours (over four years) for its V76 32K 660ns MOS memory. (The V76 is not available with core memory). Varian's stated MTBF for their V75 16K MOS memories is 55,000 hours; for 16K core memories, 73,000 hours. Here again, core is more reliable. However, a memory with a MTBF of 55,000 may hardly be considered unreliable. In addition, core memory for the V75 is available in 990ns and 660ns versions;

but V75 MOS memory has a 330ns cycle time. Therefore, it may be considered worthwhile to suffer a 25% decrease in reliability to gain a 100% increase in performance, especially in time-critical applications.

Soon, with continuing increases in MOS reliability, one can expect to gain increases in performance without suffering any loss of reliability when choosing MOS memory.

Speed. Speed is one of the two greatest advantages that MOS memories have over core memories. However, there is a speed vs power trade-off that has resulted in little or no improvement over core access and cycle times by most of the MOS memories now available in commercial computer systems. Some commercially available n-MOS memories offer access times of less than 100ns; but, because these memories require multiple power supplies or dissipate high power, they are not being widely used in commercial computer systems. These MOS memories that are being widely used dissipate less power, roughly less than 200 milliwatts, but have access times well above 500 ns. Our previous example, the VARIAN V76 memory, for instance, has a 660ns cycle time. This is not a particularly impressive speed when one considers that Systems Electronics Laboratories offer 600ns core memories. On the other hand, the Varian V75 may be bought with 330ns MOS memory, which by Varian's figures is at present even more reliable than its V76 660ns MOS memory.

Constant improvements in the speed-to-power dissipation ratio of MOS memories, and in particular n-MOS memories, will surely cause more changeovers from core to MOS in the next five years. Mostek Corporation has recently released a 4K static n-MOS RAM which achieves a maximum access time of 220ns (150ns typical) and a maximum cycle time of only 260ns while dissipating only 80 milliwatts of active power at 4 Mhertz and a very low 8 milliwatts in precharge or

standby mode. As additional low-power mode of 1.0 milliwatt is available for battery back-up operation, achieved simply by lowering the power supply voltage from 56 to 2 or 3 volts. This and future MOS technological developments will surely hasten the wider acceptance of MOS memory by computer system manufacturers.

Volatility. In many harsh environments core is still preferred because of its nonvolatility. MOS memory, of course, is volatile. However, users can operate with battery back-up for their MOS memory systems, allowing them to retain data even under conditions of sudden power loss. Most manufacturers offer battery back-up as an option for MOS memory, with a corresponding increase in price. Varian charges $500 for its Data Save power supply and battery back-up for MOS memory. This added expense must be considered when discussing the total cost of MOS memory. Thus, in terms of volatility, MOS memory with battery back-up is a viable alternative to core memory in all but the most harsh environments.

Cost. Cost is the second of two advantages that MOS memory has over core, especially if one considers the price/performance ratio. Table 9 presents the cost per bit of the various VARIAN memories. As Table 9 shows, the best price per bit is achieved with 660 ns MOS. The best price/performance ratio is also achieved with 660 ns MOS; the worst price/performance ratio is achieved with 660ns core.

At present, most manufacturers offer MOS memory at lower cycle times (better performance), but at higher prices than core memory. This is because core memory is widely used and is therefore produced in great quantities. In addition, the technology used in core manufacture is well in hand; whereas, MOS technologies are still evolving. The greatest cost in manufacturing core memory is the cost of threading the magnetic donuts themselves. This is painstaking, time-consuming work performed by hand - and is

Table 9. Price and Performance of Varian Memories:

MOS vs. Core

Computer	Cycle Time (Performance)	Technology	Price (cents/bit)	Price/ ** Performance
V75	990ns	core	1.3/1.4*	3.94/4.24*
	660ns	core	2.7	5.4
	330ns	n-MOS	3.7/3.8*	3.7/3.8*
V76	660ns	n-MOS	1.1	2.2
V77	660ns	n-MOS	1.1	2.2

* Depending upon whether parity bits (1 per byte) are included. Lower value without parity/higher valve with parity.

** Figures are based on a performance evaluation as follows:

330 ns = 1
660 ns = 1/2
990 ns = 1/3

In this way the higher the price, the higher the price/performance ratio; and, the higher the performance, the lower the price/performance ratio. This results in the best price/performance ratio being the lowest value. The price/performance ratio figures are in units of price/bit-performance.

therefore an expensive process. Because MOS memories lend themselves more readily to mass production, as MOS memory use increases and MOS technology completes its evolution, the cost of MOS memories should decrease drastically. In the meantime, MOS memories still provide the best price/performance ratio.

Conclusions. (1) Due to the decreasing price and increasing reliability of MOS memory, it should be seriously considered if not specified for future Army trainer computer systems. (2) If MOS memory is to be considered for future trainers, battery back-up should be an absolute requirement.

Computer Evaluation Criteria

Computer system criteria are divided into two types, pass/fail criteria and quantitative/qualitative criteria. There are six criteria which the AAHT computer system must meet in order to support the AAHT. Pass/fail criteria include:

a. Program protection
b. Floating point
c. Interrupt and trap handling
d. Multiprocessor support
e. CPU controllability of I/O
f. Extendability of instruction set

The first five criteria are self-explanatory. The extendability of the instruction set is important in terms of upward compatibility. If little or no extendability exists (few, if any, unused instruction codes), then to add new instructions - thereby providing new capabilities - may re-require revision of the instruction format. When the instruction format is revised, the existing software is rendered useless on the "revised" machine. The greater the percentage of possible instruction codes that are unused, the longer the existing software may be used on newer models

of the same computer, adding tremendously to the software's upward compatibility and to the length of the software life cycle.

Quantitative/qualitative criteria were established in the following areas:

a. Throughput requirement
b. Primary storage requirement
c. Secondary storage requirement
d. Peripheral requirements
e. Instruction repertoire
f. Software requirements

These areas are discussed separately below.

Throughput and Primary Storage Requirements. Sperry's approach to establishing the computer system throughput and primary storage criteria for the AAHT was to perform each of the steps detailed in the following paragraphs.

The first step was to identify the top-level, functional computer program components (i.e., aerodynamics, on-board systems, instructional features). A further break down to major computer program modules was required to achieve a high confidence factor in the areas of instruction and data counts. A list of the major computer program modules is provided in Table 10.

The second step was to determine the requirements pertaining to each computer program module, such as:

1. Extent of simulation
2. Method of implementation
3. Instructional features
4. Data availability
5. Iteration rates.

The highest iteration rate of 30 Hertz is the rate at which data must be provided to the visual system, therefore, this rate should be the minimum specified for the AAHT with a CGI visual system. The lower rates were selected based on several factors. The 15 and 7.5-Hz rates are multiples

TABLE 10. COMPUTER PROGRAM MODULE LIST

Real-Time Routines

Real-Time Operating System
Input/Output Handlers
Math Function Subroutines
I.S. Controller
I.S. Display Data
I.S. Printouts
Auto Playback/Demo
I.S. R/T Initial Condition Record
I.S. Reset
Cycle Time Verification
Procedure Monitoring and Performance Evaluation
Instrument Scaling
Fire Control / Doppler Navigation
Aerodynamics
Engines
Motion System
FLT Controls / BUCS
Fuel System
Electrical System and Auxiliary Power Unit
Hydraulic System
Terrain Mapping
Communications/Navigation
Environment (Oxygen System)
Weapons Scoring
Crash
Freeze/Parameter Freeze
Visual
Voice Recorder
Flight Instruments
Caution and Warning Panel
Icing, Pitot Static
Fire Detection (Panel)
Wheel Brakes
SAS
Flaps
Ejection
Engine Instruments, Engine Oil

Background Routines

Library Data File Handlers
Preflight Check/Calibration
Radio Nav Station Support
AN/Graphic CRT Display Generator
Real-Time Interface Equipment Diagnostic
Simulation Verification Program
Computer Program System Support Programs

of the 30-Hz rate, thus providing a constant relationship between parameter computations and ease of executive control. The 2-Hz and 1-Hz rates were selected for implementation of the instructional features of the F-16 TFS. The 2-Hz update rate will be utilized for the alphanumeric displays and performance monitoring. The 2-Hz rate is used to optimize displayed data accurately while ensuring that the display is readable. The 1-Hz rate is used for instructional features such as real-time initial conditions recording. These instructional features will occur within 40 milliseconds of the instructor action; however, they will only occur once per second. The rate selections of the remaining systems were established to provide the proper response required for simulation. Sperry has successfully simulated many gas turbine aircraft engines using a 10-Hz rate, which is less than the selected rate (15 Hz). With this iteration rate, transient engine response in starting, shutdown, acceleration and deceleration has been exactly reproduced. The recommended iteration rates for each module are shown in the second column of Table 11.

Step two provides the information necessary for step three, sizing each computer program module. Sizing for each computer module was accomplished by performing the following three tasks:

1. Determine the total number of instructions
2. Determine the total data and constant storage
3. Determine the number of instructions executed per frame

The results of these determinations are shown in the third through fifth columns of Table 11. Tasks one and two are self-explanatory. Task three is not directly related to sizing; however, it is a very important factor in determining the computer time loading (the total number of instructions that must be executed in a given time period).

SPERRY SECOR SIMULATION SYSTEMS

TABLE 11. COMPUTER PERFORMANCE REQUIREMENTS ANALYSIS

PROGRAM NAME	ITERATIONS PER SEC	MEMORY		EXECUTED INSTRUCTIONS	mSEC/ FRAME	mSEC/ CYCLE	INSTRUCTIONS/ SECOND	%FORTRAN CODE
		INSTRUCTIONS	DATA					
RT Exec/OS	30	12,000	2,000	1,000			30,000	0
I/O Handlers	30	1,000	200	300			9,000	0
I.S. Cntrllr	2	1,200	6,500	600			1,200	0
I.S. Printouts	2	400	200	300			600	60
I.S. Init.Cond.	1	150	50	150			150	0
I.S. Reset	1	120	80	120			120	0
Freeze/Para Frz	30	100	20	50			1,500	90
Playback/Demo	30	450	3,000	500			15,000	0
Voice Recorder	30	250	50	150			4,500	60
Instrmt Scaling	30	100	300	180			5,400	0
C.T. Verifictn	30	70	200	50			1,500	0
PM & PE	30	500	500	400			12,000	0
Eng Inst/Eng Oil	30	100	100	200			6,000	100
Caution/Warning	30	150	75	225			6,750	100
Motion	30	400	50	380			11,400	100
Crash	30	100	20	80			2,400	100
Icing/Pitot Stat	7.5	100	50	75			562.5	100
Fire Detect	7.5	50	25	40			300	100
SAS	30	200	10	190			5,700	100
Engines	15	900	1,000	1,300			19,500	100
Fuel	15	400	50	380			5,700	100
Hydraulic	15	300	50	200			3,000	100
Elect Sys/APU	7.5	150	10	150			1,125	100
Oxygen	7.5	100	50	50			375	100
Flaps	15	70	5	70			1,050	100

SPERRY
SECOR SIMULATION SYSTEMS

TABLE 11. COMPUTER PERFORMANCE REQUIREMENTS ANALYSIS (Con't)

PROGRAM NAME	ITERATIONS PER SEC	MEMORY		EXECUTED INSTRUCTIONS	mSEC/ FRAME	mSEC/ CYCLE	INSTRUCTIONS/ SECOND	%FORTRAN CODE
		INSTRUCTIONS	DATA					
Ejection	7.5	60	20	50			375	100
Aerodynamics	30	1,500	550	1,500			45,000	100
Flt Cntrls/BUCS	30	600	200	420			12,600	100
Visual	30	500	50	500			15,000	100
Fire Cntrl/Dop Nav	30	500	100	500			15,000	100
Terrain Mapping	30	200	150	100			3,000	100
Comm/Nav	15	500	50	350			5,250	100
Weapons Scoring	30	500	100	500			15,000	100
Wheel Brakes	7.5	30	-----	30			225	100
Math Func Subs	30	500	50	1,000			30,000	0
	15	------	-----	800			12,000	0
	7.5	------	-----	400			3,000	0
Flt Instruments	30	500	10	400			12,000	100
Data Pool			5,000					
SUBTOTALS		24,750	20,875				313,282.5	
REQUIRED SPARE		24,750	20,875				313,282.5	
TOTALS		49,500	41,750				626,565	

Real-time aircraft simulation programs are written using various types of programming techniques, such as branching and repetitive loops. The number of instructions that are executed in each frame is determined by which programming techniques are implemented; and, it is the total number of instructions executed in each frame - not module size - that determines the computer time loading. Therefore, any calculation of time-loading requirements that is not based upon the number of instructions executed per frame is invalid.

The fourth step was to calculate the total number of instructions that must be executed each second. This was accomplished by multiplying the number of instructions executed per frame by the require iteration rate (in seconds) and summing the results. This result provided the basic computer instruction throughput required for simulation program implementation.

Steps one through four result in the establishment of the computer system throughput and primary storage requirements. Table 11 shows that the total number of instructions that must be executed each second to support the AAHT is 313,282.5. With 100% spare processing time the required system throughput is 626,565 instructions per second. The total primary storage required is equal to the total number of instructions (24,750) plus the total number of data words and constants (20,875), or 45,625. With a 100% spare memory requirements, the total primary storage required for the AAHT is 91,250 words or 364,000 bytes.

<u>Secondary Storage Requirements</u>. To insure that a disc failure does not obviate trainer operation, Sperry SECOR recommends that a backup unit be provided. There are two possible approaches to providing secondary storage backup: on-line or off-line. With on-line backup, the backup units are part of the system configuration: data is simultaneously written to

both the primary disc and its backup, while being read only from the primary disc. On-line backup requires a slight increase in programming costs, decreases the system MTBF and doubles the secondary storage materials cost of each trainer. The advantages to be gained with on-line backup are (1) only a momentary interruption in the current training exercise, and (2) no loss of data recorded for playback. With off-line backup, the backup unit is physically disconnected from the computer system and sits idle until an error is detected in any of the primary units. Off-line backup offers many advantages:

1. The training exercise is interrupted only long enough to exchange disc units.
2. Secondary storage materials cost are increased only by 50% for the first trainer at any particular site. There is no increase in secondary storage materials cost for any subsequent trainer at the same site since one disc unit may serve as off-line back-up for up to four trainers.
3. Off-line backup has no inflating effect on programming costs.
4. With off-line backup the spare disc does not affect the system MTBF.

There is one minor disadvantage with off-line backup. All of the recorded data currently residing on the faulty disc unit may be lost. That is, the playback capability will not be available for the first n minutes of trainer operation after a disc exchange has been made, where n is less than or equal to the provided maximum playback duration.

Therefore, because off-line backup provides the most economical approach to secondary storage backup, while imposing only a limited curtailment of capabilities, Sperry SECOR recommends that a single off-line moving head disc be provided with only the <u>first</u> trainer at each site.

Timing considerations require that record/playback data reside on a dedicated disc. Therefore, at least two discs are

required, one for program and data storage (mission data disc) and a second for playback and automatic demonstration storage (playback/demo data disc). Mission data should also be contained on the playback/demo disc. This assures that if the mission data disc fails - due to a head crash, for example - the operating system and data will not be destroyed: it may simply be copied from the playback/demo disc to the back-up disc after the mission data disc has been replaced. Table 12 lists the storage allocation for both discs.

Files should be structured so that disc accessing requires a minimum amount of head movement. Considering the continuous writing/reading required by record/playback, CRT and record/playback data files should be continuous, providing minimum head travel on the respective disc drives.

Peripheral Requirements. *In order to facilitate* software configuration management, Sperry SECOR recommends two separate system configurations: a support center computational system configuration to be installed at the first site, Fort Rucker, and a general computational system configuration without permanent software modification capabilities to be installed at all other sites. The support center configuration shall be identical to the general configuration except for the addition of those peripheral and software units necessary for software development and permanent modification. All permanent changes to software should be made at the support center site. The general configuration sites will provide the capability to change data base items and mission support data (such as radio facilities data) only.

TABLE 12. MASS STORAGE ALLOCATION

Mission Data Disc		Playback/Demo Data Disc	
Operating System and Program Storage*	5 Mbytes	Operating System and Program Storage*	5 Mbytes
Data File Storage	5 Mbytes	Playback (5 min)	1 Mbyte
Terrain Mapping Data	9 Mbytes	Demo (10 min X 10 demos)	20 Mbytes
		Data File Storage	5 Mbytes
		Terrain Mapping Data	9 Mbytes
TOTAL	19 Mbytes	TOTAL	40 Mbytes

*This includes computer/peripheral diagnostics.

Support Center Peripherals. One card reader and one line printer are required for software development and maintenance. A keyboard unit is also required if not readily available at Fort Rucker.

General Configuration Peripherals (All Sites). An interactive device is required for machine operator interface. Sperry SECOR recommends a CRT/keyboard/cassette/hard copy unit. A display terminal offers two main advantages over teleprinter terminals: extensive editing and block transfer of the edited message to the computer. The cassette capability allows on-site changes to the data base items and mission support data. It also allows new or updated software, generated or modified at the support center site, to be entered into the general configuration site computer.

Instruction Repertoire Requirements. Whether FORTRAN or assembly language is used, text handling is much easier and efficient with byte manipulation instructions. Also, because many simulation modules are Boolean systems (lights, switches, etc.) byte-sized flag representations are necessary. In addition, since simulation modules utilize many single-bit DI's, bit manipulation instructions are also required for easy and efficient coding of simulation software. Therefore, any candidate computer should have an adequate range of both byte and bit manipulation instructions, which include logical operations, in addition to the usual complement of instructions.

Software Requirements. The required computer program system software components are shown in Figure 41. Because the Operating System and the FORTRAN compiler have a direct effect on the real-time performance of the simulation programs, a list of capabilities required for support of real-time flight simulators was prepared for use in evaluating the candidate vendor's offerings in these two areas.

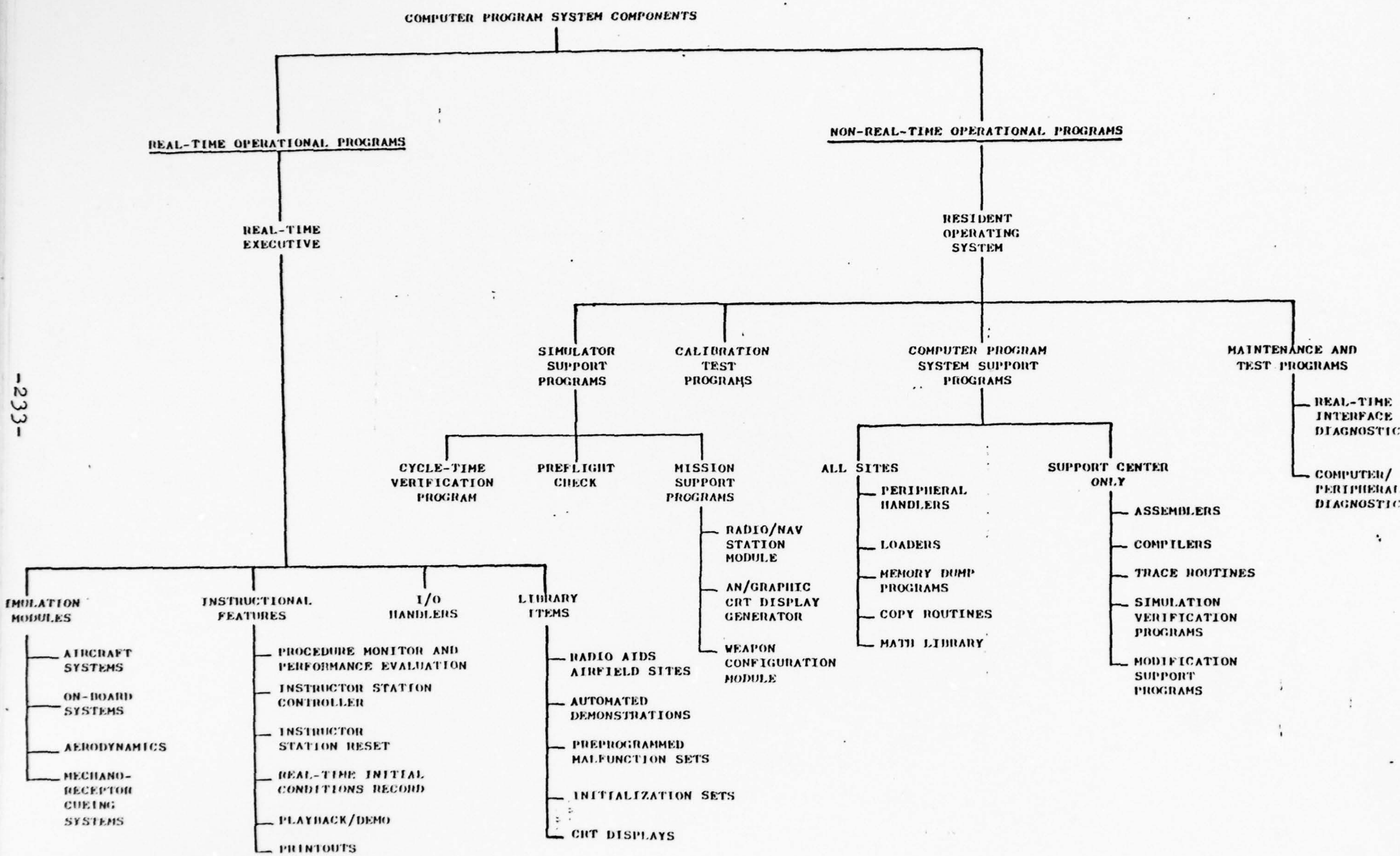


FIGURE 41. COMPUTER PROGRAM SYSTEM COMPONENTS

In order to adequately support a flight trainer, an operating system must have the following specific capabilities:

1. Event-driven multitasking
2. Capability of supporting multiple foreground tasks and a batch-oriented background task concurrently
3. At least 30 software priority levels
4. Interrupt and trap handlers
5. On-line resolution of external references for foreground tasks
6. Dynamic memory allocation of foreground and background tasks
7. Software and operator task activation
8. Queued I/O
9. Re-entrant task intercommunication and coordination routines, available to foreground tasks
10. Global common memory
11. Position-independent symbolic global common references
12. File management and assignment
13. Three levels of system generation:
    1. Rebuild disc (complete system generation)
    2. Alter resident OS portions while keeping permanent files intact
    3. Load a fresh copy of OS from disc
14. Servicing of all standard peripheral devices

Required FORTRAN compiler capabilities are as follows, ranked in order of descending importance:

1. Should make efficient use of machine architecture.
2. Compiler output should be object code.
3. In-line coding of Intrinsic Functions.
4. Should pass variable between registers if a single variable is passed in a subroutine or function call.
5. Should include byte and bit manipulation capabilities.
6. Should handle in-line assembly language code.
7. Should be a diagnostic compiler similar to WATFOR/WATFIV on the IMB 360, to DITRAN on the UNIVAC 1108,

or to FORGO on the Harris Slash 5. That is, it should provide execution time checking to detect more subtle run-time errors. Such checks should include detection of (a) undefined variables, and (b) subscripts that exceed array bounds as defined in their dimension statements.

8. Should provide the precise location of compile-time errors within the source program.
9. Should allow expressions to contain mixed-mode elements.
10. Encode and Decode facilities (to provide storage-to-storage data manipulations).
11. Multiple entry to functions or subroutines.
12. ERR Function.

Priorities were established on the basis of compiler use for simulation modules only. Highest priority was given to those features that generate the most efficient code. Next highest priority was given to those features that provide the best debug aids. Lowest priority was given to those features which are merely convenient for the applications programmer.

Survey of Available 32-Bit Minicomputers

Available Models. There are only two domestic manufacturers that provide true 32-bit minicomputers: Systems Engineering Laboratories (SEL) and Interdata. A number of minis, such as the Data General S/230 Eclipse or the PDP 11/70 have 32-bit instruction formats; some, such as the Interdata 7/32, may even be purchased with 32-bit CPU register bus organization. However, all of these minis, with few exceptions, have 16-bit memory bus widths. Therefore, to perform a 32-bit operation they must do two loads and two stores. If the CPU register bus organization is only 16 bits, they must also use two CPU registers. All of this drags down their effective throughput. Only the Interdata 8/32 and the SEL 32/35, 32/55 and 32/75 have both 32-bit CPU register organization and a 32-bit memory bus width. Of these, the Interdata 8/32, SEL 32/35 and SEL 32/55 are available presently. The SEL 32/75 will be available in October 1977. All four of these computers meet all of the pass/fail criteria established previously. Results of the evaluation of these computer systems against the established qualitative/quantitative criteria are discussed below.

Throughput. To calculate the average instruction execution rates for candidate computers, illustrated in Tables 13 through 16, the first step was to determine the overall instruction mix by analyzing the implementation methods, the languages used, and the extent of their use for each program module. Second, the products of the fractional usage for each instruction class and the instruction class execution time of the candidate computer were calculated. The summation of these products yielded the average execution time of a single instruction in microseconds. The inverse of this execution time yielded the average execution speed or the instruction throughput of the computer under consideration. The significant difference between the SEL 32/75 and previous SEL 32 modles is due to the change to a new firmware-implemented floating point unit which operates on multiple bits in parallel. Only the SEL 32/75 and the Interdata 8/32 can meet the 100% spare processing time requirements without additional CPU's.

Primary Storage. All four of the candidate computers may be configured with 1 Mbyte of primary storage, which far exceeds the 0.364 Mbyte requirement for the AAHT. The SEL 32/75 may be configured with as much as 8 Mbytes of primary storage.

Secondary Storage. Both manufacturers supply both 40 and 80-Mbyte moving head discs. Without considering the spare storage requirement, a 40-Mbyte capacity is sufficient for both the mission data and playback/demo data discs. If 40-Mbyte discs were chosen, four moving head disc drives would be required to meet the 100% spare storage requirement. This is by no means an economical approach. Therefore, two 80-Mbyte discs are recommended.

TABLE 13. SEL 32/35

AVERAGE INSTRUCTION EXECUTION RATE

Instruction Class	Fractional Usage	usec/Instruction	Product
Load, Store	.30	1.8	.540
Add, Subtract*	.08	1.35	.108
Add, Subtract (Fl. Pt.)	.04	2.7	.108
Branch, Transfer**	.20	1.35	.270
Compare*	.05	1.35	.068
Multiply	.05	5.7	.285
Multiply (Fl. Pt.)	.04	7.3	.292
Divide	.01	9.0	.090
Divide (Fl. Pt.)	.01	9.3	.093
Boolean*	.20	1.35	.270
Shift (5 places)	.02	2.2	.044
	1.00		2.168

Average Instruction Execution Rate 461,255 Instructions/sec

* Register-to-Register operations require 0.9 μsec, Memory Reference requires 1.8 μsec (average 1.35 μsec).

** Branch requires 0.9 μsec if fall through or 1.8 μsec if branch taken (1.35 μsec average).

Fl. Pt.: Single Precision Firmware Floating Point Arithmetic

TABLE 14. SEL 32/55

AVERAGE INSTRUCTION EXECUTION RATE

Instruction Class	Fractional Usage	usec/Instruction	Product
Load, Store	.30	1.2	.360
Add, Subtract*	.08	0.9	.072
Add, Subtract (Fl. Pt.)	.04	3.0	.120
Branch, Transfer*	.20	0.9	.180
Compare*	.05	0.9	.045
Multiply	.05	5.7	.285
Multiply (Fl. Pt.)	.04	6.1	.244
Divide	.01	9.0	.090
Divide (Fl. Pt.)	.01	9.1	.091
Boolean*	.20	0.9	.180
Shift (5 places)	.02	2.2	.044
	1.00		1.711 usec

Average Instruction Execution Rate 584,454 Instructions/sec

* Register-to-Register operations require 0.6 μsec, Memory Reference required 1.2 μsec (average 0.9 μsec)

** Branch Requires 0.6 μsec if fall through or 1.2 μsec if branch taken (0.9 μsec average)

Fl. Pt.: Single Precision Firmware Floating Point Arithmetic

TABLE 15. SEL 32/75

AVERAGE INSTRUCTION EXECUTION RATE

Instruction Class	Fractional Usage	usec/Instruction	Product
Load, Store	.30	1.2	.360
Add, Subtract*	.08	0.9	.072
Add, Subtract (Fl. Pt.)	.04	1.95	.078
Branch, Transfer**	.20	0.9	.180
Compare*	.05	0.9	.045
Multiply	.05	5.7	.285
Multiply (Fl. Pt.)	.04	3.95	.158
Divide	.01	9.0	.090
Divide (Fl. Pt.)	.01	4.1	.041
Boolean*	.20	0.9	.180
Shift (5 places)	.02	2.2	.044
	1.00		1.533

Average Instruction Execution Rate 652,316 Instructions/sec

* Register-to-Register operations require 0.6 μsec, Memory Reference requires 1.2 μsec (average 0.9 μsec)

** Branch Requires 0.6 μsec if fall through or 1.2 μsec if branch taken (0.9 μsec average)

Fl. Pt.: Single Precision Firmware Floating Point Arithmetic

TABLE 16. INTERDATA 8/32

AVERAGE INSTRUCTION EXECUTION RATE

Instruction Class	Fractional Usage	μsec/Instruction	Product
Load, Store**	.30	1.6	.480
Add, Subtract	.08	0.8	.064
Add, Subtract (Fl. Pt.)	.04	1.8	.072
Branch, Transfer*	.20	1.8	.360
Compare	.05	0.8	.040
Multiply	.05	3.1	.155
Multiply (Fl. Pt.)	.04	2.1	.084
Divide	.01	5.7	.057
Divide (Fl. Pt.)	.01	3.9	.039
Boolean	.20	0.8	.160
Shift (5 places)	.02	2.9	.058
	1.00		1.569

Average Instruction Execution Rate 637,349 Instructions/sec

* Register-to-Register operations require 0.4 μsec, memory reference operations require 1.25 μsec (average 0.83 μsec)

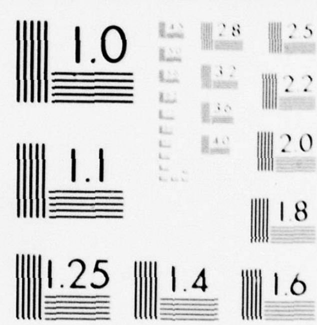
** Load from memory operations require 1.25 μsec, store operations require 2.00 μsec (average 1.6 μsec)

Fl. Pt.: Single Precision Hardware Floating Point Arithmetic

AD-A064 401 SPERRY SECOR FAIRFAX VA F/G 14/2
AH-64 FLIGHT AND WEAPONS SIMULATOR CONCEPT FORMULATION STUDY. V--ETC(U)
SEP 77 J L DICKMAN, H KESTENBAUM, P W CARO N61339-77-C-0048
UNCLASSIFIED SE-622-CFS-114-VOL-2 NL

3 OF 3
AD
A064401

END
DATE
FILMED
4-79
DDC



MICROCOPY RESOLUTION TEST CHART

A comparison of the 80-Mbyte moving head disc drives that are provided by the candidate computer manufacturers is provided in Table 17. Note that the operational features of both disc drives are identical. However, the SEL-provided disc drive is the optimum dirve since it provides a larger actual storage capacity at a much lower price when purchased directly from Control Data Corporation. The MSM80 is available only from Interdata.

Peripherals. Both the SEL 32/75 and Interdata 8/32 may be configured with the peripherals required for the support center. Interdata supplies a CRT, keyboard and hard copy device and inter-tape cassette unit to meet the operator terminal requirement. SEL does not provide the required terminal equipment; however, the SEL can be interfaced to a Hazeltine H2000 CRT/keyboard with thermal printer and dual tape cassette unit.

Instruction Repertoire. Both SEL and Interdata provide four bit manipulation instructions which, although not exactly the same, are functionally equivalent. Both SEL and Interdata provide byte manipulation instruction that facilitate text handling. However, SEL's instruction repertoire was judged to be superior since only SEL's instruction set includes instructions to perform logical operations (AND, OR, exclusive OR) on byte values. This is important in handling boolean flags. Since Interdata's instruction set does not allow a byte value from memory to be logically combined with a register's contents, flags must be stored as halfword values. With the great number of boolean flags that are used in real-time aircraft simulation, this is extremely wasteful of memory.

Software. Table 18 compares the various capabilities of the SEL RTM and Interdata OS32MT operating systems. Table 19 is a similar comparison of the SEL FORTRAN IV and Interdata FORTRAN VI compilers.

Table 17. 80MB Disc Drive Comparison

	SEL	Interdata
Model Number	9320	MSM80
Actual Storage Capacity (bytes)	72,687,360	67,200,000
Transfer Rate	1.2 Mbyte	1.2 Mbyte
Rotational Speed	3600 RPM	3600 RPM
Access Time:		
Minimum	7 ms	7 ms
Average	30 ms	30 ms
Maximum	55 ms	55 ms
Cost:		
Disc & Controller	12,700*	25,000**

* Controller purchased from SEL at $5,000, 80 Mbyte Disc Drive Model 9762 purchased from CDC at $7,700.

** Disc and Controller must be purchased together.

TABLE 18. OPERATING SYSTEM CAPABILITY COMPARISON

Capability	SEL	Interdata
Event-driven multitasking	yes	yes
Simultaneous multiple foreground tasks and a single background stream	yes	yes
Minimum of 30 software priority levels	yes	yes
Interrupt and trap handlers	yes	yes
On-line resolution of external references for foreground tasks	yes	yes
Dynamic memory allocation of foreground tasks	yes	yes
Software and operator task activation	yes	yes
On-line diagnostics run under the operating system	yes	no
Queued I/O	yes	yes
Reentrant task intercommunication and coordination routines available to foreground tasks	yes	yes
Global common memory	yes	yes
Position independent symbolic global common references	yes "datapool"	no
File management and assignment	yes	yes
Three levels of system generation: 1. Rebuild disc. 2. Alteration of resident OS portions while keeping permanent files intact. 3. Load a fresh copy of resident OS from disc.	yes	yes System generation software functions "tailored to customer needs".
Servicing of all standard peripheral devices	no No paper tape reader handler	no No Versatek printer/plotter handler

Table 19. FORTRAN Compiler Capability Comparison

Priority	Capability	SEL	Interdata
1	Efficient use of machine architecture	yes	no
2	Compiler output is object code	yes	no Output must be assembled.
3	In-line coding of intrinsic functions	yes	yes
4	Inter-register transfer of a single argument in a subroutine or function call	yes	?
5	Byte and bit manipulation	yes	yes
6	In-line assembly language code	yes	yes
7	Execution-time error checking during compile	no	no
8	Precise location of errors	yes	yes
9	Expressions containing mixed mode elements	yes	yes
10	Encode and Decode	yes	yes
11	Multiple function and subroutine entry	yes	yes
12	ERR function	yes	yes

SEL ranked higher in the evaluation of operating systems. This is due to the fact that the SEL's operating system provides position-independent symbolic global common references and on-line diagnostics that run under the operating system. Without non-ordered, position-independent common area (or datapool), every module and subroutine that references the datapool must be reassembled or recompiled, when the datapool order changes. With position-independent datapool, when the datapool order changes, modules and subroutines that reference the datapool need only be relinked. Thus, the only reason to reassemble or recompile is to make a change to the module itself - not to change a datapool reference or to relocate the module.

SEL's FORTRAN IV compiler also ranked higher for two very important reasons. First, Interdata's FORTRAN VI compiler does not create object code that may then be linked and loaded. Instead, it produces assembly language source code that must then be assembled before linking and loading may occur. This two-step process is not only inefficient, it also creates the possibility that the compiler will not produce error-free assembly code. Second, and more important, although Interdata claims its compiler makes efficient use of machine architecture, this does not appear to be the case. Sperry Systems Management has run FORTRAN benchmarks on both the SEL 32/55 and the Interdata 8/32. The results of these benchmarks (refer to Table 20) have been inconsistent with the calculated throughput data. According to the throughput data, the Interdata 8/32 should execute faster than the SEL 32/55. However, the benchmarks show that the SEL 32/55's times for the thirteen benchmark programs are very close to the Interdata 8/32 times. In fact, the SEL 32/55 actually ran five of the benchmarks faster than the Interdata 8/32. This suggests that the SEL 32/55's slower instruction execution times are compensated for by

Table 20. Benchmark Results*

Program	Core (words)		Time (in seconds)	
	SEL	Interdata	SEL	Interdata
PLASMA	364	508	0.052	0.070
RSTCHK	7646	8140	2.08	2.974
ACOS(X)	358	476	0.090	0.111
ALOG(X)	288	328	0.107	0.990
ASIN(X)	318	436	0.112	0.133
ATAN2(A,B)	228	270	0.060	0.058
ATAN(X)	274	350	0.157	0.131
COS(X)	369	408	0.075	0.067
EXP(X)	278	326	0.065	0.047
A^X	198	228	0.027	0.019
$ALOG_{10}(X)$	158	190	0.042	0.042
SIN(X)	318	380	0.052	0.051
SQRT(X)	281	284	0.615	0.462

*SEL 32/55 benchmarks were run under SEL's RTM (5.0) Operating System using SEL's FORTRAN IV Compiler (REV H) on November 6, 1975, and again on January 6, 1976. Identical results were obtained both times.

Interdata 8/32 benchmarks were run using Interdata's FORTRAN VI Compiler on March 17, 1977.

its more efficient compiler. Conversely, Interdata's compiler makes such inefficient use of the 8/32 architecture, that its compiler loses the time advantage provided by the 8/32's faster instruction execution speeds. The fact that, for each and every benchmark program, the SEL FORTRAN IV compiled programs used less core than did the Interdata FORTRAN VI compiled programs also supports the conclusion that the SEL compiler is more efficient. One may also reason that the same benchmark programs, compiled with the SEL FORTRAN IV compiler and executed on the SEL 32/75, would yield even faster execution times than the 32/55 and would better the 8/32 execution times for more, if not all, of the thirteen benchmark programs.

In conclusion, SEL's software is judged to be superior to Interdata's.

<u>I/O Structure</u>. The Interdata 8/32 has two 16-bit busses to which I/O controllers and interfaces may be attached. Refer to Figure 42. Low speed devices such as teletypes, CRT's card readers, line printers, etc., attach to the multiplex (MUX) bus via an interface. The CPU controls the MUX bus. Parameters governing the I/O for each device are stored in tables located in main memory. Due to the timeshared nature of the firmware controller, the aggregate I/O rate on the MUX bus must not exceed 64,000 transfers (0.128M bytes) per second. Up to 1024 devices may share the MUX bus. The second Interdata I/O bus is the DMA bus. The DMA bus is controlled by a hard-wired Buffered Selector Channel (BSELCH) which can support sixteen high speed devices such as discs, mag tapes, analog input systems and custom interfaces. Unlike the MUX bus which steals memory cycles and processor cycles from the CPU, the DMA bus connects directly to the Memory Bus Controller, not the CPU. The processor merely initiates the action of the BSELCH via the memory bus controller. After initiation the BSELCH controls the actual DMA data transfer. The maximum data rate on the DMA bus is 5.98M bytes per second for one device at a time operating in burst mode.

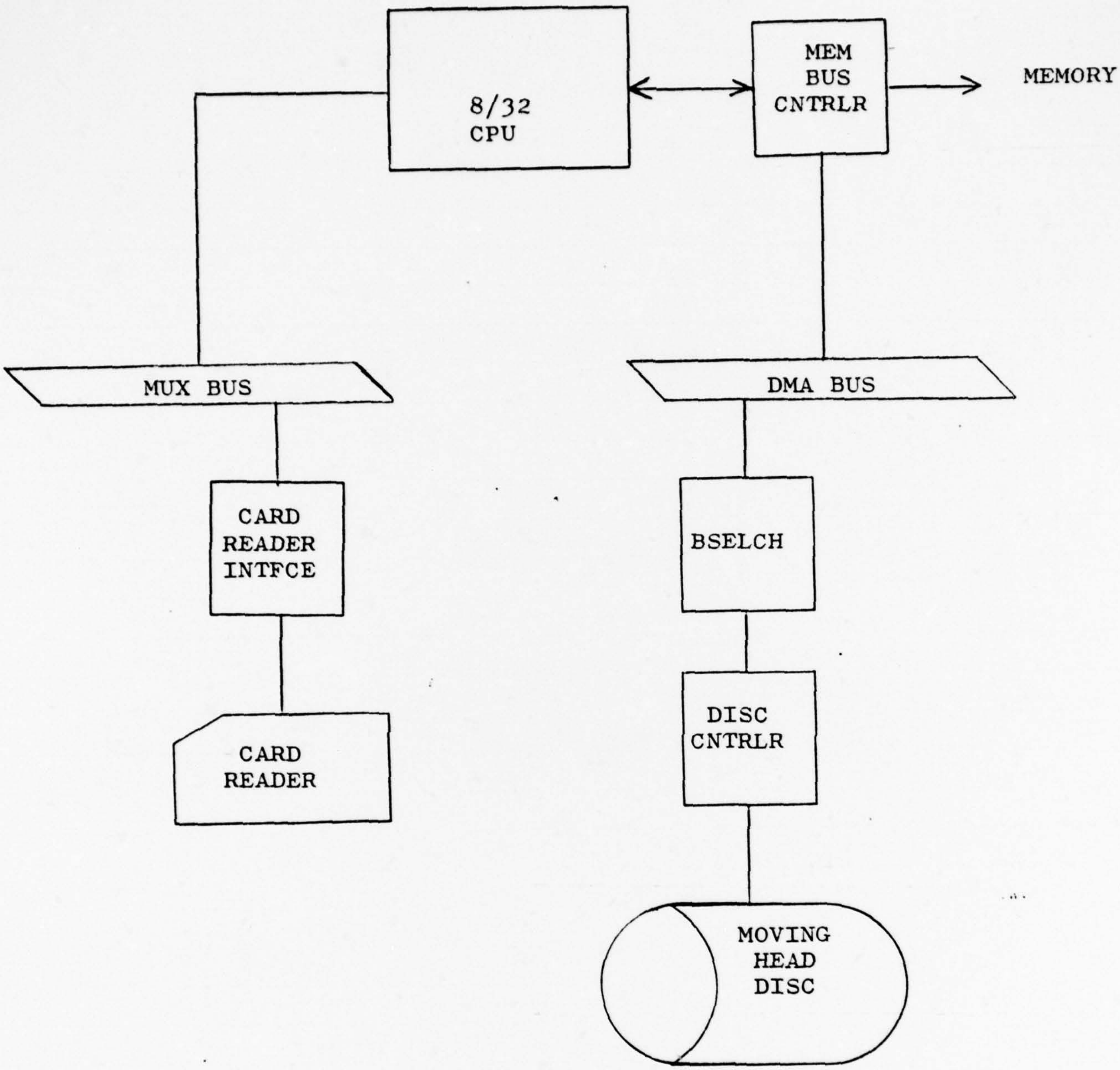


FIGURE 42. INTERDATA 8/32 I/O SYSTEM DIAGRAM

The input/output structure of the SEL 32 is oriented to the structure and operation of the SEL Bus. The SEL Bus is a 32-bit wide data path which operates at the basic rate of 26.67 Mbytes per second. The data rate capability of the SEL Bus is the limiting factor in overall I/O thruput rates. All input/output operations on a SEL 32 system are performed under the control of Input/Output Microprogrammable Processors (IOM). Each IOM is an independent 16-bit firmware programmed micro-computer. All I/O on the SEL 32 is done on a direct memory access basis. Data transfer rates for standard SEL IOM's are 1.2 Mbytes per second per IOM. Total I/O transfer rate is limited to the 26.67 Mbyte per second transfer rate of the SEL Bus. Data transfer operations through an IOM are initiated by the execution of a Command Device instruction which causes a data transfer address and transfer count to be sent to the IOM. The IOM then controls the entire block transfer of data into memory. At the completion of the block transfer, the IOM will notify the CPU that the I/O is done by activating the I/O interrupt for the channel. The CPU can interrogate the status of the IOM and determine the current position of the transfer address' and transfer count register.

The Input/Output Microprogrammable Processor (IOM) is the basic hardware structure for all standard SEL 32 peripheral device controllers. The IOM is also used for all real-time interfaces. Each IOM consists of three functional parts: a SEL Bus interface, a Microprogrammable Processor (MP) and some device dependent interface logic. For the most part, the device interface logic consists of drivers and receivers for matching signal levels with the external device(s). Except for the device interface, and the firmware which is implanted in the control memory of the MP, all IOM's are identical. The standard SEL 32 products that use the IOM include the following:

a. TLC Controller
b. Cartridge Disc Controller
c. Moving-Head Disc Controller
d. Fixed-Head Disc Controller
e. Magnetic Tape Controller
f. General Purpose I/O Module (GPIO)
g. General Purpose Multiplexer Controller (GPMC)
h. Asynchronous Data Set Interface (ADS)
i. System Control Panel Controller

Conclusion. The SEL 32 I/O bus is twice as wide as the Interdata 8/32. The SEL 32 maximum I/O throughput is four times greater than that of the Interdata 8/32. All I/O is accomplished via DMA on the SEL 32: only discs and tapes and special interfaces use DMA on the Interdata 8/32. All I/O channels are microprogrammed on the SEL 32: only the low speed channels are microprogrammed on the Interdata 8/32. The SEL 32's I/O structure is more oriented toward fast, high volume, real-time applications than is the I/O system of the Interdata 8/32 which is oriented toward the interfacing of many low-speed devices such as in data concentrator or communication front-end applications.

Growth Capabilities. All of the candidate computational systems' primary storage is expandable up to 1 Mbyte with the exception of the SEL 32/75, which is expandable up to 8 Mbytes. The mass storage units can be expanded by adding additional disc drives per controller, up to four for both SEL and Interdata, or by additional controllers and disc drives. The input/output system for both computational systems can be expanded by adding additional logic I/O racks. The processing capacity for either system can be expanded by adding additional CPUs and interfacing via shared memory. The SEL shared memory system will support up to a maximum of 20 computer systems, and each single CPU may access up to six shared memories. The Interdata shared memory system will support up to 14 CPUs.

The SEL 32/75 computer system offers two alternatives to adding additional CPUs. The first is a Writeable Control Storage Option. This option allows microprogrammed (firmware) implementation of user programs, such as math and function subprograms, thereby reducing the CPU utilization by an approximate factor of 4 to 1. The second option is a Regional Processing Unit (RPU). Like the first option it is microprogrammable. Each RPU can be thought of as an extension of the main processor complete with its own arithmetic logic unit, registers, memory, etc. Each RPM is thus a processing node whose local identity, or function, can be assigned dynamically by the main processor for complex content switching, association, content addressing, and similar functions that typically require very high levels of linked parallelism. The Interdata 8/32 system offers only Writeable Control Store.

A synopsis of growth capabilities is presented in Table 21 . Clearly the SEL 32/75 has the greatest growth potential. The Interdata 8/32 rates second in growth capability, since its WCS option is a more economical approach than that of adding additional CPU's.

Cost Analysis. A cost analysis was performed for two candidate computer configurations that can meet the 100% spare processing time requirements without a multi-computer configuration - the SEL 32/75 and the Interdata 8/32. The total configuration costs are based on the configuration shown in Figure 43. The cost analysis was divided into three areas for closer comparison: they are CPU equipment for all systems, peripheral equipment for first system, and peripheral equipment for all systems. As Tables 22 and 23 show, the total configuration costs for the SEL 32/75 and the Interdata 8/32 are very close.

Table 21. Candidate Computer System Growth Capability Synopsis

	SEL 32/35	SEL 32/55	SEL 32/75	Interdata 8/32
Current Maximum Memory Capacity	1 Mbyte	1 Mbyte	8 Mbyte	1 Mbyte
Current Processor Addressing Capabilities	16 Mbytes	16 Mbytes	16 Mbytes	1 Mbyte
Discs Per Controller	4	4	4	4
Maximum CPUs Per Shared Memory	20	20	20	14
Maximum Amount of Shared Memory	512 Kbytes	512 Kbytes	512 Kbytes	512 Kbytes
Alternatives to Adding Additional CPUs				
WCS	no	no	yes	yes
RPU	no	no	yes	no

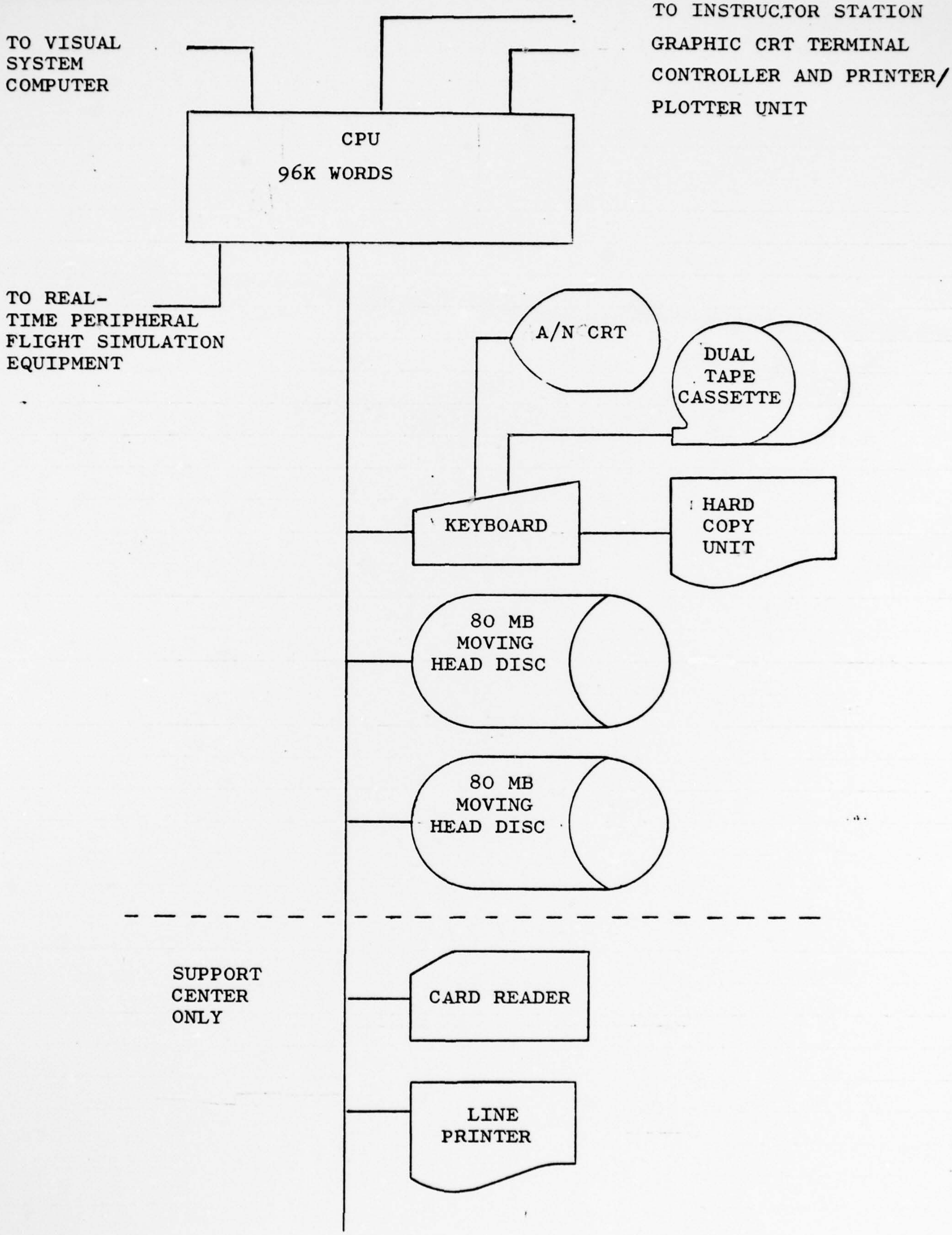


FIGURE 43. AAHT COMPUTER SYSTEM CONFIGURATION

TABLE 22. SEL 32/75 COMPUTER SYSTEM

AAHT CONFIGURATION COSTS

PART A:

CPU EQUIPMENT - ALL SYSTEMS

Item	Qty.	Model No.	Description	Total Price	Total Maint.
1.	1	2312	SEL 32/75 Computer Pkg. w/131,072 bytes of 600 ns core memory.	$ 68,200	$ 470
2.	1	2342	High-Speed Floating Point	6,000	60
3.	1	2345	Real-Time Option Module	2,700	20
4.	1	2142	System Control Panel	3,000	25
5.	1	2145	Hexidecimal Display	600	5
6.	2	2354	Memory Package - 131,072 bytes, 600 ns	34,000	400
7.	1	2336	Memory Carriage Ext. 600/900 ns	3,500	30
8.	1	7410	Analog/Digital Interface RTP	3,500	30
9.	1	9122	Asynchronous Data Set Interface	3,500	25
10.	3	9132	High-Speed Data Interface	12,000	90
			TOTAL	$137,000	$1,150

TABLE 22. SEL 32/75 COMPUTER SYSTEM

AAHT CONFIGURATION COSTS (Cont.)

PART B:
PERIPHERAL EQUIPMENT - ALL SYSTEMS

Item	Qty.	Model No.	Description	Total Price	Total Maint.
1.	2	9762	CDC Moving Head Disc Drive 80MB	$15,400	
2.	2	9010	SEL Moving-Head Disc Controller	19,000	90
3.	1	H2000	Hazeltime Alphanumeric CRT	1,850	
4.	1	4350	Hazeltime Hard Copy Printer	1,900	
5.	1	700	Hazeltime Dual Tape Cassette Unit	675	
			TOTAL	$29,825	

PART C:
PERIPHERAL EQUIPMENT - FIRST SYSTEM

Item	Qty.	Model No.	Description	Total Price	Total Maint.
1.	1	9210	Card Reader - 300 CPM	3,000	55
2.	1	9226	Line Printer - 600 LPM	16,000	200
3.	1	9004	TLC Controller	*	*
			TOTAL	$19,000	$255

*This is included in the SEL 32/75 Computer package.

TOTAL CONFIGURATION COST - $185,825

TABLE 23. INTERDATA 8/32 COMPUTER SYSTEM
AAHT CONFIGURATION COSTS

PART A:
CPU EQUIPMENT - ALL SYSTEMS

Item	Qty.	Model No.	Description	Price	Maint.
1.	1	M83-025	Model 8/32C Processor with 131,072 bytes of 750 ns core memory	$ 51,900	$500
2.	1	M83-310	Memory Expansion 131,072 bytes	20,000	180
3.	1	M83-312	Memory Expansion 131,072 bytes	19,500	180
4.	2	M49-035	8/32C System Expansion Chassis	1,400	-
5.	1	M83-102	Hexidecimal Display Panel	350	-
6.	1	M83-111	High Performance Floating Point	6,500	40
7.	1	M83-107	Processor/Memory Parity	1,000	-
8.	1	M49-050	50 Amp Power Supply	1,050	10
9.	1	M48-000	Universal Clock Module	750	5
10.	1	M73-105	Extended Selector Channel	1,000	10
11.	3	M48-013	Universal Logic Interface	2,100	-
12.	1	M70-104	LSU Controller	600	10
13.	1	M70-107	32-bit LSU Loader	250	-
14.	1	M49-042	AC Panel	N/C	-
15.	1	M49-040	System Cabinet	925	-
			TOTAL	$107,325	$935

TABLE 23. INTERDATA 8/32 COMPUTER SYSTEM
AAHT CONFIGURATION COSTS (Cont.)

PART B:
PERIPHERAL EQUIPMENT - ALL SYSTEMS

Item	Qty.	Model No.	Description	Price	Maint.
1.	1	M46-600	Model MSM80 Disc and 1X4 Controller	$25,000	$250
2.	1	M46-601	Second MSM80 Disc	18,000	200
3.	1	M46-030	Fox 1100 Terminal	1,295	15
4.	1	M46-056	Current Loop Cable	60	-
5.	1	M46-055	Current Loop Connection	30	-
6.	1	M48-024	Current Loop Printerport	125	-
7.	1	M46-060	Carousel 30	2,475	35
8.	1	M46-400	Intertape System	4,200	40
9.	1	M49-040	System Cabinet	925	-
			TOTAL	$52,110	$540

PART C:
PERIPHERAL EQUIPMENT - FIRST SYSTEM

Item	Qty.	Model No.	Description	Price	Maint.
1.	1	M46-235	Card Reader Interface	990	10
2.	1	M46-238	400 CPM Card Reader	3,060	40
3.	1	M46-206	Line Printer Interface	990	10
4.	1	M46-209	600 LPM Line Printer	17,150	110
			TOTAL	$22,190	$170

TOTAL CONFIGURATION COST - $181,625

Vendor software costs, however, are very different, as shown in Table 24. All costs are based on the purchase of software provided on magnetic disc. Only a source version is purchased, when available, since object version may be generated from the source version by the contractor. Software need be purchased only with the first trainer. SEL's price is lower, this time however, by 33%.

Survey Conclusion. Since the SEL 32/75 rated higher than the Interdata 8/32 in the areas of throughput, secondary storage, software, instruction repertoire, growth capability and cost, Sperry SECOR recommends the SEL 32/75 as the optimum choice for the AAHT computer system.

TABLE 24. COMPUTER SYSTEM SOFTWARE COSTS

PART A:
SEL SOFTWARE COSTS

Item	Qty.	Model No.	Description	Price
1.	1	595-321001	Real Time Monitor (Source)	$1,500
2.	1	595-321011	Macro Assembler (Source)	750
3.	1	595-321012	FORTRAN IV (Source)	1,500
4.	1	599-32103X-XXX	All Off-Line Diagnostics (Source) 22 @ $50 each	1,100
			TOTAL	$4,850

PART B:
INTERDATA SOFTWARE COSTS

Item	Qty.	Model No.	Description	Price
1.	1	S90-006-81	OS/32MT (Source and Object) on 80MB Disc and Documentation Pkg.	$5,300
2.	1	S90-213-81	FORTRAN VI (Object)* & Document Pkg.	800
3.	1	S90-205-81	CAL Macro Processor (Object)* & Documentation Pkg.	750
4.	1	S90-405-81	Multimedia Diagnostic (Object)*	400
			TOTAL	$7,250

*Interdata does not supply Source version

INTERFACE SYSTEM

The interface system, which is the focal point of all system hardware, should be designed so as to provide ease in maintenance as well as to be easily programmed to access any or all channels of a particular type of I/O.

Computer access to the interface should be via a random or a block transfer. Both of these methods are required to allow the programmer the most flexible means of transferring data to the interface. Block transfers are the most commonly used in today's trainers because of the computer time required and the ease in programming. Since the latest generation of computers allows the transfer of data without cycle-stealing time, it is logical to set up the I/O transfer once for a large block and to continue the execution of the simulator programs. However, during maintenance and occasionally in the simulator software a need arises to access one device in the I/O without affecting the other devices. As a result, random access would be required to perform this task. This feature is very important when the interface has a failure in its control logic. The operator, by setting up a single transfer, will be able to diagnose a problem without concern about other transfers being made.

For testing the interface, a closed loop I/O test should be provided that checks each discrete and each channel over the range of the particular channel. Discrete inputs should be checked individually in both the high and low states. After testing of the discrete inputs, a test should be run on the discrete outputs. This test would toggle the discrete outputs from one state to another. The output of the discrete outputs would be routed to a corresponding discrete input that has been automatically disconnected from its regular trainer input.

Analog testing should be done in such a manner that the full voltage swings of the analog devices are tested. The analog input testing should test at least three different voltage levels. Likewise, analog output testing should be done using at least three different voltage levels and should be routed for testing through existing analog inputs.

Synchro testing should include the testing of the synchro converters through the range of the converter. The testing of all converters should be under computer control and all switching should be controlled by the computer.

The interface system should be designed in such a manner as to have as much noise immunity as possible. Analog inputs and outputs should be required to have differential inputs and outputs respectively. Twisted pair lines for the analog signals should be used.

It is recommended that a commercially available interface system not be used for the AAH simulator. Some of the reasons behind this are:

- I/O contains many features that cannot be used in a simulator.
- I/O test is difficult to perform.
- Equipment is unnecessarily large.

Most commercial interface systems are designed to interface with several different computers, with each computer system having its own requirements. As a result of trying to provide an interface applicable to most needs, the interface manufacturer has built in many features that are never used by a simulator manufacturer but are paid for by the customer.

The needs of I/O testing as described previously do not lend themselves to a commercial interface. In order to

facilitate such a test condition, all interface signals would require routing through an array of relays, such as T Bar. This leads to many more solder and crimp connections and more wire, resulting in a higher probability of noise susceptance and a more difficult system to maintain.

For the above reasons, the commercial interface requires considerable equipment occupying several cabinets. This problem can be alleviated by having an interface specifically designed for a simulator.

An interface system designed for a simulator's needs requires very little space. The I/O testing for digital and analog equipment can be performed on the individual board rather than going through relays, etc. This is accomplished by having standard analog boards and standard digital boards versus having standard analog input, analog output, digital input, and digital output boards. The standard boards would contain, for example, one digital input word and one digital output word. The boards would contain all the necessary hardware for self test. Discrete outputs would be of two types: (1) a high speed TTL device for interfacing with other TTL hardware, and (2) slower transistor switching with a higher output current. The slower switching devices would be used for interfacing with lights, relays, etc., where fast switching speeds result in high noise levels.

Another feature that should be incorporated into an interface is an analog output memory. Due to occasional halts of the computer, either intentional or non-intentional, the sample and hold capacitors discharge themselves, resulting in instruments and other analog driven signals changing. The solution is to incorporate a memory which allows the sample and hold to be updated, regardless of whether the computer is running. This will prevent any

droop in the analog output voltage, which in turn could put an undesired voltage on an instrument, amplifier, etc., unless additional switch circuitry is used.

WEAPON DELIVERY SYSTEMS

The visionic gear located in the cockpit and gunner stations is the principal equipment used in weapon delivery. The equipment provides a feedback for the gunner and pilot for aiming his selected weapons. The heart of this equipment is the fire control computer (FCC) with the Hellfire missile system, IHADSS, TADS, PNVS, and Doppler system providing and receiving data from the FCC and each other.

Fire Control Computer

The fire control computer performs computations necessary for target acquisition and weapon ballistic compensation, and supplies logic commands required to control the fire control subsystem. The computer provides both azimuth and elevation aiming information for the 30mm gun, Hellfire missiles, and the 2.75-inch rockets. The aiming point prediction is based upon information from the laser or manually-selected range, TADS, helmet or direct sight angles, air data and aircraft flight parameters, targeting-navigation geometry, and weapon/projectile ballistics.

The fire control computer used in the aircraft is a 16-bit, parallel, general purpose computer. The memory capacity of the computer is 16K words of random access, non-volatile, read-only memory, and 2K words of random access, volatile, scratch pad memory. The memory speed is approximately one microsecond.

The interface for the on-board computer is housed with the computer. The interface receives as a minimum the following types of signals:

Inputs	
Discrete	18
Synchro	3
DC Analog	7
Digital Serial	3
AC Reference	1
Mux Data Bus	2
Outputs	
AC Analog	5
DC Reference	1
Discrete	2
Digital Serial	1
Mux Data Bus	2

The Mux data buses are multiplex data channels per MIL-STD-1553. They are capable of communicating with up to 32 devices.

In the simulator there would be three alternative ways of simulating the fire control computer. These three ways are (1) using the on-board computer, (2) emulating the on-board computer program, or (3) generating a compiler so that the on-board computer program can be loaded into one of the simulator's computers. The advantages and disadvantages of each should be studied in detail before any requirement is stated in the trainer specification.

Trainer-Peculiar Features. A trainer, because of its need for versatility, has many features that create problems when aircraft parts, especially on-board computers, are used. Some of these features are Freeze, Reset, Playback, Failures, and Demonstrations.

When an on-board computer is used, problems arise

concerning how to stop the computer from executing any of its program for a period of time but to allow the computer to continue to send the last computed results at "freeze" to the various equipments. This process can be accomplished by modifying the aircraft program for the simulator, but it defeats the main reason for using an on-board computer, i.e., having the capability of keeping the computer program up to date.

With a compiler method, "freeze" would require in the program executive a means of executing only the output transfer and not executing any other portion of the program. This method would be fairly simple: the I/O routine for the on-board program would probably not be called in a compiler method of simulation because of each computer having its own trainer-peculiar I/O. As a result, the I/O would be under control of the simulator executive, not the on-board computer executive.

An emulated program is an ideal solution for the "freeze" problem because all operations are totally controlled by the trainer executive. The programs can be modeled to include all of the features previously mentioned (Freeze, Reset, etc.).

Record/Playback, Demonstration, and Reset to a specific point all create similar problems when the on-board computer is used. The main difficulty is the method of programming the computer back to a particular point in time. This problem is handled in the emulated and compiler methods of simulation by storing all flags and past values required on the disc. The problem would be more difficult with the compiler method but could be solved. Normally there is no way of solving this problem when using the on-board computer. If the training exercise did not require the

fire control computer to reinitialize to a particular point, the problem would be eliminated altogether. But, with all the systems that are controlled by the fire control computer, much would be lost without this feature.

The last problem to be dealt with in trainer-peculiar features concerns failures. One of the great advantages of trainers is to teach the student first how to recognize a failure and secondly how to accomplish the required corrective actions. If an on-board computer were used, all failures dealing with the computer would have to be examined carefully to determine whether or not they could be accomplished and still obtain all of the proper indications. Since many signals go over the MUX bus and serial data lines, a large number of possible failures would be very expensive or impossible to implement with an on-board computer. With a compiler or emulator method, many failures, if not all, could be simulated by incorporating them in the I/O routine or, in the case of the simulation method, in the computer software.

As a result of the above discussion on trainer-peculiar features, it can be concluded that the best simulation of the fire control computer is by emulation. This method will allow the greatest flexibility and the least risk in solving the problems described. The compiler method will allow many of the problems presented to be overcome, but the risk in being able to solve all of the problems must be considered as medium at best. High risk would be to use the on-board computer and expect to get all of the trainer-peculiar features. This method is considered the undesired approach for these features.

Software Updating. When an aircraft fire control computer is used in a simulator, one of the major problems is how will the simulator computer program be kept up to date with the aircraft computer program. This problem is often not examined closely enough to prevent degraded training from occurring. With a new computer being developed for a new aircraft, at least three major revisions will normally be made to the aircraft computer software between trainer design freeze and acceptance. The result is an out-of-date trainer when it is supposedly ready for training, and a trainer that is difficult to test because of inability to define the computer program as it existed at the trainer design freeze date. This situation is normally encountered when emulating an on-board program. When using a compiler method of simulation, the program can be kept up to date by loading the new aircraft tape if the locations of program calls and the data pool have not been changed. If the on-board computer were used, the tape could immediately be loaded and run. The only problem that could occur then would be hardware additions. This problem, however, would affect all types of simulation and would require action in any case.

It can be concluded that the best method for keeping the fire control computer up to date is to use the on-board equipment. By using the compiler method, a risk would be incurred that some other programs might have to be changed in order to update the basic program. Such changes, however, should not require a major effort. The emulation method is the most costly in terms of keeping the system up to date and could result in the system being far behind the aircraft. If this method were used, Sperry SECOR would recommend that means be developed to allow program changes to be incorporated as soon as required, and that the software for the fire control computer be

designed so as to allow fast incorporation of changes.

Monitoring Controls and Displays. In order to fulfill his role in training, the instructor must know what the student pilot and gunner are doing. To obtain information on how the student is performing in operating his fire control computer and associated equipment, the instructor must have knowledge of what the student's mission is, what he has done, what he is currently doing, and what he is seeing. This requires the instructor to, in some way, be capable of monitoring all switches and control panels associated with the fire control computer. This requirement applies whether the instructor is positioned behind the student or at a remote station. Provisions must be made, preferably by a CRT display, to monitor this information. If the instructor is behind the student, he must be provided full monitor capability including displays and switch settings that could very easily not be visible from the instructor's position.

When the fire control computer is simulated for emulation this problem is easily resolved. The simulation computer needs to know all of this data to perform its computations, hence, the data is already available in a usable form. The same condition exists for the compiler method of simulation, since all of the inputs and outputs are generated in the simulator computer. The use of an aircraft computer, however, creates several problems. One problem is how to obtain the switch settings that are being transferred over the MUX bus. This problem can be solved but requires more hardware than normally would be required. One solution is to provide a repeater readout, employing additional hardware to pick up the data and

decode it. If processing is done in the terminal unit, this also would have to be duplicated. Another problem is to provide a readout to the instructor on what is being displayed on the computer terminal, and to allow the instructor to look at other parameters not selected for display by the student. This last aspect, i.e., providing a readout of various data in the fire control computer regardless of student selection, cannot be overcome unless the fire control computer is modified. This would then defeat the purpose of using the on-board computer.

Conclusions regarding this particular problem are that either emulation or compiling are the preferred methods to simulate the fire control computer. The use of the actual computer would sacrifice to some degree the training effectiveness of the trainer and would require additional hardware.

Interfacing. Many fire control computers have complicated interface requirements, especially when they are used to control and receive data from an inertial measurement system. However, the interface requirements for the AAHT aircraft fire control computer do not appear to be extensive or complicated. This should result in easy interfacing with the on-board computer if it were used. Likewise, interface requirements when simulating the fire control computer by the emulation or compiler methods do not appear to present any problems. Most of the data is already in the simulation computer; so, in fact, the I/O requirement is reduced from the on-board computer method.

One other problem, timing, is encountered in terms of interfacing with the on-board computer or by compiling the on-board program. Although timing is not considered a

difficult problem to solve, it can be very expensive. A fire control computer's iteration rate is normally much faster than the simulation program's fastest rate. This means that, to avoid any anomalies that might occur because data seen by the on-board computer program is not being updated fast enough, many modules will require a faster iteration rate. As a result, this will increase the number of computers required for the simulation problem.

Based on the above discussions, it is evident that advantages and disadvantages can be found regarding the various ways to simulate the fire control computer. Much weight should be placed on how the trainer will be affected in its training capability. Also, one should look at the total cost to determine the cost effectiveness, and include in this cost impact due to keeping the trainer at the same level as the aircraft. With all of the factors mentioned and realizing the requirements that must be met to accomplish the training mission of the AAHT, Sperry SECOR recommends that the fire control computer be simulated by compiling the on-board program into a language suitable for use in the simulator's computer. This method would allow the trainer program to be kept up to date at a reasonable initial cost. All the problem areas mentioned in this discussion have little impact on the trainer if the compiler method is used.

Visionics

The visionic equipment associated with the fire control system are the Target Acquisition and Designation System (TADS), Pilot Night Vision System (PNVS), and the Integrated Helmet and Display Sight System (IHADSS). A fire control symbol generator is used to produce the

symbology for the pilot and copilot integrated helmet display system and the copilot's direct view display. Video from the TADS TV, TADS FLIR, PNVS IR, video recorder, and missile infrared imaging seeker (when installed) is also supplied to these systems.

Simulation of the visionics equipment should be accomplished via the visual system, specifically through the CGI processor. A single processor channel would drive the simulated TADS displays used by the gunner. Two CRTs would be connected to the same video input. One would act as the gunner's panel CRT. The other would be observed through the gunner's TADS eyepiece. For normal viewing distances, the panel CRT subtends about 20° in the gunner's vision, while the eyepiece shows him a 64° field. Thus, magnifications are different for the two displays, as summarized in the chart earlier in this section.

The pilot's only CRT display is through his helmet-mounted display, which normally will carry the IR from the PNVS for night operations. Both the pilot's and gunner's helmet-mounted display can show any TADS or PNVS video at their selection, but only the IR data shows at unity magnification in this display. A fire control symbol generator is integrated with the video chain to the visionics to produce symbology for weapons status and control. The Hellfire missile Infrared Imaging Seeker (IRIS) video can also be selected for display.

The TADS/PNVS sensors and the gunner's panel displays would thus be simulated with CRTs and optics, while the IHADSS could be stimulated by the visual and computer modules. The integration of the visionics with the windshield display would allow the crew to correlate their views in a way that implements the full mission training requirements of the AAH-FWS.

All weapons that the AAH can carry should be included in the AAHT. This would include the gun, rockets, and Hellfire missile. The simulation should provide operational training for all weapons in all modes. For the Hellfire missile, the instructor should be given the capability of acting as the illuminator. Failures, such as missfires, should be provided.

Target Designation

The Hellfire missile has two basic operational modes: direct fire and alternate laser engagement. The direct fire mode can be performed either autonomously or with a scout or ground designator. In this mode the designator illuminates the target before launch to allow missile lock-on. The missile has a search angle coverage of 11 degrees, which increases with the number of missiles loaded and active because of their offset from each other and the bias added to the scan when multiple missiles are active. After launch the missile will home on the designated target. This means that the designator, either remote or the AAH, must illuminate the target until impact.

The alternate laser engagement mode has three sub modes. One of these is a pseudo-direct firing mode. In this mode, the missile range can be increased in a poor visibility condition. A remote designator which is relatively close to the target would illuminate the target. The AAH located further away can detect the reflected energy only with the very sensitive Target Acquisition Designation System. This will allow the azimuth required for launching of the missile to be obtained without missile lock-on. As the missile approaches the target after launch the less sensitive seeker on the missile will acquire the target for homing guidance.

The second method, indirect fire, is used to launch a missile behind a physical mask such as trees, terrain, or buildings. The bearing to the target must be known and the missile aligned to this bearing within specified limits. The missile will then acquire a lock-on after launch if it is in the lock-on envelope.

The third method of releasing a missile in the alternate engagement mode is the pseudo indirect mode. This mode is used to maximize designator survivability. The missile is launched on a predetermined trajectory. Therefore the bearing to the target must again be known, either by seeing the target or by knowing where the target is located. The missile is launched without a lock-on. During the missile's terminal phase of flight, the target is illuminated to give the missile guidance information.

From the above discussion on the Hellfire delivery, it is evident that there must be coordination between the pilot and gunner. To provide training for this coordinated effort and for the operation of the system, the role of the AAHT and its implementation have to provide, as complete as possible, training in all modes of operation and scoring. The direct mode of operation with a remote designator will require the instructor to be capable of illuminating a target. This would be done with a keyboard input rather than with the visual display. Scoring the mission should be based on pilot setup of the helicopter with respect to the target, missile aiming, and system operation. Direct fire autonomously requires more effort from the training pilot/gunner. In this case, the target should be set up but not illuminated by the instructor. The target should be seen on the visual display as well as the cockpit displays used for visual reference. In addition the target should have the capability of moving at some speed and direction to simulate tank movement. Now the problem for the pilot/gunner is to align

the designator to the target so that the Hellfire missile can lock on the target and maintain this alignment until detonation. In this case the scoring should not only take into account the parameters mentioned previously, but also the ability of the designator to continuously illuminate the desired target especially in terms of scoring a hit or miss based on actual target coordinates. This will require the ballistics of the Hellfire missile to be simulated so that calculations in terms of maneuverability versus distance to the target can be generated to compute the impact point of the missile for comparison with the targets actual coordinates.

The alternate laser engagement modes present some difficulties in terms of being able to simulate the real world. One of the major problems is determining line of sight when hills, buildings, etc., are incorporated into the scene. This would be required to allow simulation of the indirect firing mode. To provide line of sight agreement between the visual and the laser systems, Sperry SECOR would recommend that the visual system determine if an obstacle is masking the target. This method would allow full simulation without a digital landmass. The pseudo direct mode can be implemented by allowing the instructor to have a control that would vary the strength of the laser return. The simulated Hellfire missile would then not be able to receive the laser return at a normal range if the return was attenuated. However, the TADS could possibly receive it because of its higher sensitivity. The pseudo indirect mode can be simulated by the instructor or the pilot/gunner not illuminating the target till after launch. To determine the pilot/gunner performance, scoring will have to take into account the missile ballistics, the initial missile alignment, and the system operation.

NAVIGATION AND COMMUNICATION SYSTEMS

The navigational equipment on the AAH consists of an ADF system, doppler system and a heading-attitude reference system, HARS. These systems are used to provide an airframe reference in terms of position and attitude. The ADF system is a UHF system used to provide bearing to non-directional beacon stations. The simulation of this system should include preprogrammed radio facilities with their associated call letters. Bearing information would then be calculated and displayed based on various switch settings. In addition, any anomalies in the ADF system such as offsets when on the ground, jitter, etc., should be included in the simulation. The doppler system is used for determining ground speed and drift, and computing a position based on this information. The simulation of the doppler system should include all modes of operation that exist in the AAH, including any warm-up time. The heading-attitude reference system provides to the pilot and to other avionics equipment, heading and attitude information. The simulation of this system should include the erection rates, system downgradement, modes of operation, and failures requiring the pilot to go to a back-up mode of operation.

The communication equipment on board the AAH is used for communication with the various air facilities and with the scout helicopter or ground personnel. Communication with the air facilities is handled over the UHF radio and VHF-AM radio. Most of the tactical communications will be handled via the VHF-FM radio. The pilot and gunner both have communication equipment to talk to ground facilities as well as an inter-communication system. Since the pilot and gunner both have communication capability, Sperry SECOR recommends that controls be provided allowing the instructors to act as different radio facilities. The instructors should be given an indication of which trainee

is communicating and the radio he is using. Along with this, each instructor should be allowed to determine whose audio he will receive. This will provide the greatest flexibility of allowing the instructors to act as ground facilities. In addition, the instructor should be given the capability of transmitting over the secure voice network, KY28 and KY58. This will provide a means for the trainees to familiarize themselves with degraded voice communications while in a tactical environment. It is also recommended that line of sight for the VHF-FM be handled by the visual system. This will allow interruptions in communications because the AAH has positioned himself out of line of sight of the scout, whether it be air or ground.

RELIABILITY AND MAINTAINABILITY

Introduction

The primary objective of reliability and maintainability programs for simulator devices is to maximize total system availability for training during the projected usage.

This section of the study addresses the reliability and maintainability requirements for the FWS, and provides definitions, discusses program management and recommended R&M tasks, and presents initial MTBF and MTTR prediction estimates and conclusions.

Definitions

Reliability is defined as the probability that an equipment will continue to function correctly for a specified period of time without failure under a prescribed condition of use. Maintainability is an expression of the probability of equipment being restored to operating status within allowable time limits using available test equipment, facilities, trained personnel, spare parts and procedures (texts).

R&M Program Management

Reliability and maintainability are listed as Integrated Logistic Support (ILS) elements (ref: NAVTRAEQUIPCEN Bul. 40-1) from the standpoint of their maintenance preventive roles. However, both remain as functions of design to permit engineering apportionment of performance goals to subsystems and components. Since reliability and maintainability have a direct influence on operational availability, they must be considered strongly in equipment readiness, performance and cost effectiveness trade-offs. Surveillance over changes in both design and support is required to prevent degradation.

Trade-offs are conducted to improve system design and support and to provide a continual narrowing down of initial configuration designs and ideas until a firm production baseline is established.

AH-64 FWS Program Tasks

Major reliability and maintainability tasks to be included in the AH-64 FWS program are listed below. Although the overall responsibility is assigned to ILS, many inputs will be required from other interfacing disciplines such as design and systems engineering, standardization, human and safety engineering, etc.

Task

- Organization Implementation - Contractor
- Interface Compatibility - Design Configuration
- Subcontractor and Vendor Compliance - R&M Programs
- Establish R&M Data Collection System
- Parts Testing - Stress Analyses
- Failure and Repair Time Analyses
- Program and Design Reviews
- Contract Formal Reports - DD Form 1423 (CDRL)
  R&M Program Plans
  Quarterly Status Reports
  Test and Demonstration Plans and Reports
- Establish Formal Prediction Model and Goals
- Conduct Reliability Test
- Maintainability Demonstration (on site)

AH-64 FWS Prediction Model

Figure 44 is the initial reliability and maintainability prediction model for the major system model areas

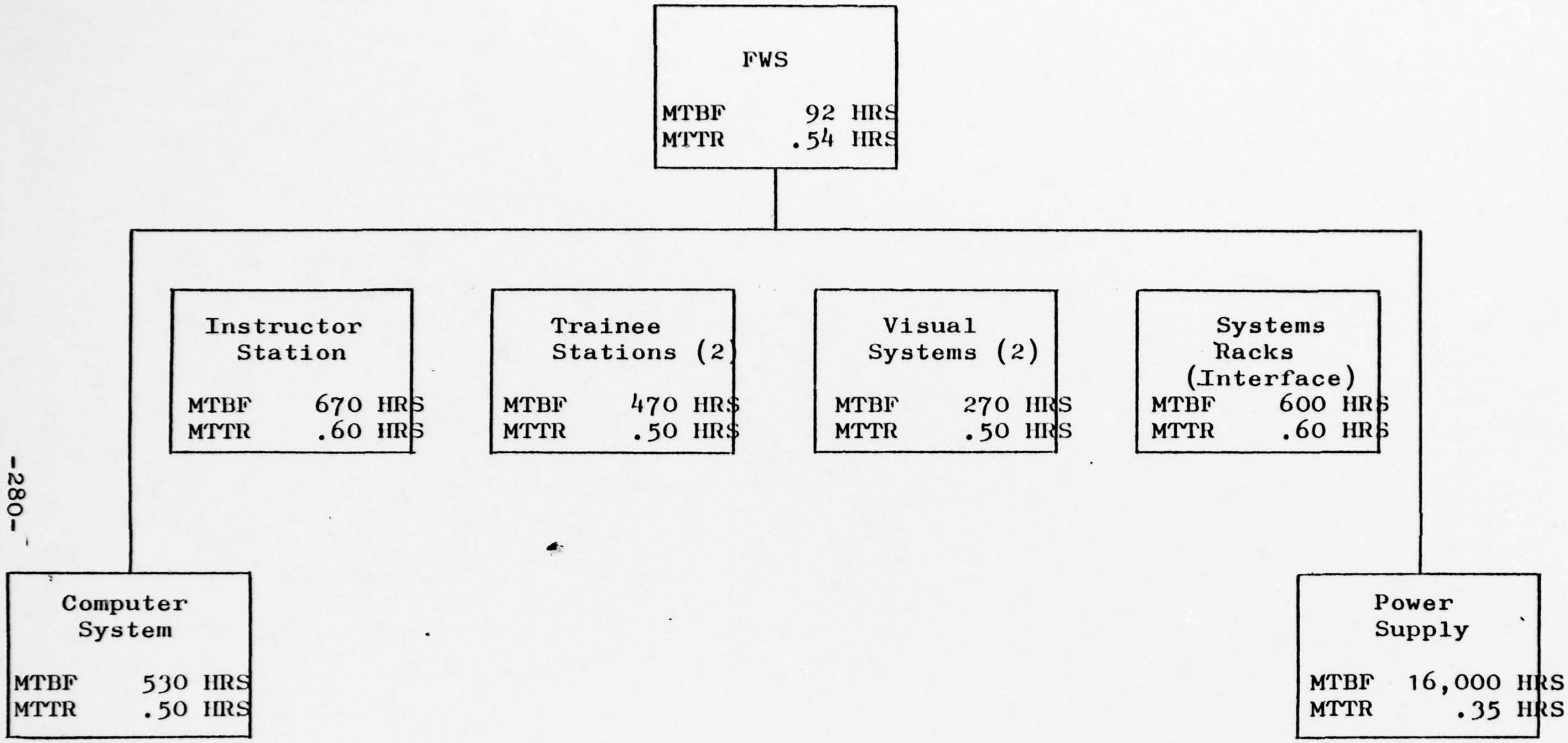


Figure 44

AH-64 FWS Initial System Prediction Model

of the FWS. The model is serially arranged in a "family tree" format. The model was developed from the design and configuration concepts contained in this study and is based on the following R&M data sources:

Vendor supplied
Sperry SECOR experience
MIL-HDBK-217B
MIL-HDBK-472

Current predictions indicate a 92 hour MTBF, and a .54 hour MTTR. Inherent availability is .9942.

It is planned during the final report and specification preparation to further detail the model to include identification of the major subsystem areas. Any changes resulting from this refinement will be incorporated in the final report and detailed specification.

Conclusions

The AH-64 FWS design essentially is based on existing state-of-the-art technology and proven Sperry SECOR designs and designs of potential sub-contractors. This lends confidence in the quantitative reliability and maintainability estimates as established in the initial system model. Further, these initial estimates have been compared with actual values resulting from tests and demonstrations on comparable equipment configurations as that proposed for the AH-64 FWS. In these cases there has been very reasonable agreement between the predicted and actual values.

Daily Readiness Test

Indirectly related to maintainability and reliability is the daily readiness test. A daily readiness test is necessary as a positive indicator that the trainer is capable of operating properly. This will allow the instructor to begin training sessions with some assurance that the mission could be completed without equipment malfunctions. Further, if a minor malfunction is detected, the instructor can avoid usage of the defective equipment, or advise the student appropriately.

The daily readiness test would be used as the initial system test for each operating day, for a maintenance troubleshooting aid, and as a system test performed before the preventive maintenance period. This test could be performed by a solitary operator in approximately fifteen minutes.

The test would consist of a number of modules (subtests) which would normally be done in sequential order as determined by the computer program; a test module could consist of several discrete steps. For use as a maintenance tool, any individual module could be called up via the instructor's console. The in-cockpit tests would be performed with the aid of a hand-held test set (e.g. a DRU) and a check list. The test set would display an ordinal test number (corresponding to the module) and a mnemonic (corresponding to the step). These would correlate with test headings on the check list.

The check list would contain information detailing the tasks to be performed by the operator for each step, e.g. observing that the indicator lamps on a certain panel are blinking in a given sequence, or that the indicator pointers on instruments are moving in a recognizable, distinct pattern.

The test set would contain controls which would permit the operator to step from one module to the next, to "freeze"

the step being performed, and to step the automatic program backward or forward to any desired test. A go/no-go indication would be provided to inform the operator if a particular step requiring operator action (such as actuating a switch) had been performed successfully.

Any failed module steps would be displayed at the instructor's console.

A typical test sequence would be as follows: The operator would enter the command for the daily readiness test at the instructor's console. An execute command would cause the automatic sequence to begin. (The test would go directly to a particular desired module if its mnemonic was entered before the command to execute the test sequence.)

The console would display a message indicating that the I/O module was being performed. At the completion of this module, an appropriate message would be displayed. Another execute command entry would cause a test pattern for the instructor station CRT's to be displayed. A further execute command would cause another test pattern to appear; possibly five different test patterns would be used to comprehensively test this subsystem.

Following this CRT test module, the instructor's console would display a message indicating that the cockpit test sequence was to be performed next. The operator would take the test set to the trainee station and connect it.

At the beginning of the cockpit test sequence, the CGI system would automatically begin a comprehensive automated pipeline test module. A message displayed at the instructor's console would indicate that this module was in progress. At the module sequence, the instructor's console would display a message indicating pass or fail of the CGI pipeline module.

The operator (in the cockpit) would perform tasks as indicated by the test set and the check list. Performance of these tasks would provide comprehensive checks of all instruments, digital displays, annunciators, and avionics. Tests of equipment which require an inordinate amount of time and which also test components with a low failure rate (e.g. gear switch and throttle) would be at the end of the cockpit module sequence and could be skipped as a group by exiting from this sequence. Any module skipped would be so designated on the instructor's console.

After completion of the in-cockpit test modules, the operator would leave the cockpit, close the canopy, and go to the instructor station, where he would enter a command to begin a motion system module. All degrees of freedom would be checked by this module.

After completion of all test modules intended to be performed, the operator would be able to obtain a hard copy printout of the results of the entire test. The printout would be available at the printer plotter, located possibly in the computer area or near the instructor station.

INTEGRATED LOGISTIC SUPPORT

Introduction

Integrated Logistics Support (ILS) is a concept designed to ensure that equipment delivered to the field can be adequately and efficiently supported for its expected useful life. ILS is defined by NAVTRADEVCEN Bul. 40-1A as "a composite of the elements necessary to assure the effective and economical support of a system or equipment at all levels of maintenance for its programmed life cycle."

The following paragraphs present in summary form the objectives, elements and management requirements of an ILS program. Discussions pertaining to ILS are based to a large extent on past and present contracts with NTEC.

ILS Objectives

The objectives of an Integrated Logistics Support program are twofold:

- To ensure completion of the logistic support items on schedule
- To ensure that the logistic support items are adequate to fulfill their intended purpose.

Both objectives must be accomplished to provide adequate support for the device once it has been delivered.

To accomplish the first objective, two conditions must be met. The first is the availability of sufficient manpower to accomplish the required task within the time allowed. The second is the availability of sufficient input information from the design group early enough in the program to permit the task to be completed on schedule.

The availability of sufficient manpower is an administrative problem which requires a complete under-

standing of the effort required to accomplish the work and the ability to forecast the number and types of people which must be made available during the program. Top management is responsible for ensuring that these personnel needs are satisfied.

The second objective of the Integrated Logistic Support program - to ensure that the support items are adequate to fulfill their intended purpose - also requires that two conditions be met. First, the personnel engaged in preparing the items must be competent and experienced. Second, the support items must be accurate and must reflect the device exactly as delivered. This condition is the most difficult to achieve and can only be accomplished with a strong, comprehensive logistic support program coupled with a rigorous drawing control procedure and quality assurance program.

ILS Program Elements

In general, an ILS program for a simulator system consists of the following major areas:

Reliability
Maintainability
Standardization
Technical Publications (O & M Hdbk, PMS, etc.)
Provisioning
Contractor Conducted Training
Support Equipment
Spares/Repair Parts
Interim Support
Subcontractor and Vendor ILS Compliance

These program elements are further iterated in logistics support analyses and life cycle costs conducted throughout the program period.

ILS Program Implementation and Management

Program implementation and management are assigned to a logistics coordinator or logistics manager to insure overall control and achievement of the ILS tasks. The Integrated Logistic Support Management Plan (ILSMP), a contract deliverable report, is a comprehensive plan fundamental to the management and execution of the ILS program. Milestone schedules which are an integral part of the Plan interrelate both contractor and Government activities which are necessary to accomplish the required logistics support contract elements on schedule. The ILSMP is reviewed and monitored on a regular basis to identify or forecast progress and/or possible slippages. Formal presentations and discussions of ILS program status are accomplished during progress reviews. Problem areas, if any, are identified and resolved at these times.

ILS Requirements and the AH-64 FWS

An ILS program on a future AH-64 FWS procurement contract will require detailed planning and coordination in meeting the necessary support requirements. This is based both on size of the simulator system and equipment complexity. However, no major problems are envisioned in the ILS areas since a large portion of the equipments are commercially available or of proven design for which ILS related data is readily (or near readily) available.